PB81-111445

Source Category Survey
Refractory Industry

Radian Corp.
Durham, NC

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Mar 80

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-80-006
March 1980

PB81-111445

Air

EPA

Source Category Survey: Refractory Industry

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA 450-3-80-006

2.

3. RECIPIENT'S ACCESSION NO.
PB81 111445

4. TITLE AND SUBTITLE
Source Category Survey: Refractory Industry

5. REPORT DATE
March 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
M. S. Jennings and A. H. Laube

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Radian Corporation
3024 Pickett Road
Post Office Box 8837
Durham, NC 27707

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-02-3058

12. SPONSORING AGENCY NAME AND ADDRESS
DAA for Air Quality Planning and Standards
Office of Air, Noise, and Radiation
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report documents a study assessing the need for new source performance standards (NSPS) for the refractory industry. The industry is examined with respect to products product uses, plant distribution, and growth potential. Emission sources and species are identified and emissions from these sources are quantified. Present methods of air pollution control are examined along with their effectiveness. State regulations applying to the industry are summarized. Based on the estimated industry growth in new sources and the emission reduction possible through the use of best demonstrated control, an estimate is made of the total emission reduction achievable through NSPS. This estimate and other factors indicate that development of NSPS for the industry is not warranted.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Refractories Castable Refractories Ceramic Fibers Kilns Arc Furnaces Particulate Control Equipment		13-B

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

EPA-450/3-80-006

Source Category Survey: Refractory Industry

Emission Standards and Engineering Division

Contract No. 68-02-3058

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

March 1980

This report has been reviewed by the Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Office of Air, Noise, and Radiation, Environmental Protection Agency, and approved for publication. Mention of company or product names does not constitute endorsement by EPA. Copies are available free of charge to Federal employees, current contractors and grantees, and non-profit organizations - as supplies permit - from the Library Services Office, MD-35, Environmental Protection Agency, Research Triangle Park, NC 27711; or may be obtained, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Publication No. EPA-450/3-80-006

TABLE OF CONTENTS

Page

1. SUMMARY.. 1-1
   1.1 INDUSTRY DESCRIPTION........................ 1-1
   1.2 PROCESS DESCRIPTION......................... 1-2
   1.3 EMISSIONS................................... 1-3
   1.4 CONTROL SYSTEMS............................. 1-4
   1.5 STATE REGULATIONS........................... 1-5
   1.6 RECOMMENDATIONS............................. 1-6
2. INTRODUCTION.................................... 2-1
   2.1 STUDY OBJECTIVE............................. 2-1
   2.2 SOURCE CATEGORY DEFINITION.................. 2-1
   2.3 LEGAL REQUIREMENTS.......................... 2-2
   2.4 APPROACH.................................... 2-3
3. CONCLUSIONS AND RECOMMENDATIONS................. 3-1
   3.1 CONCLUSIONS................................. 3-1
      3.1.1 General................................ 3-1
      3.1.2 Source Category Definition............. 3-2
      3.1.3 Growth Trends.......................... 3-3
      3.1.4 Emission and Controls.................. 3-4
      3.1.5 NSPS Emission Reduction Potential...... 3-5
   3.2 RECOMMENDATIONS............................. 3-8
4. DESCRIPTION OF INDUSTRY......................... 4-1
   4.1 SOURCE CATEGORY DESCRIPTION................. 4-1
      4.1.1 Definition............................. 4-1
      4.1.2 Classification......................... 4-2

TABLE OF CONTENTS (Continued)

Page

4.1.3 Extent of Production Facilities.................... 4-8

4.1.4 Special Industry Considerations.................... 4-9

4.2 INDUSTRIAL PRODUCTION TRENDS.................... 4-11

4.2.1 Historical Patterns.................... 4-11

4.2.2 Projections.................... 4-14

4.3 PROCESS DESCRIPTION.................... 4-16

4.3.1 Production of Fired Brick and Shapes.................... 4-18

4.3.2 Production of Fused Products.................... 4-25

4.3.3 Tar & Pitch Operations.................... 4-25

4.3.4 Production of Ceramic Fiber.................... 4-26

4.4 REFERENCES.................... 4-27

5. AIR EMISSIONS DEVELOPED IN THE SOURCE CATEGORY.................... 5-1

5.1 PLANT AND PROCESS EMISSIONS.................... 5-1

5.1.1 Refractory Brick Kiln.................... 5-2

5.1.2 Arc Furnace Emissions.................... 5-11

5.1.3 Tar and Pitch Operations.................... 5-13

5.1.4 Ceramic Fiber Emissions.................... 5-15

5.2 UNCONTROLLED EMISSIONS FROM TYPICAL PLANTS.................... 5-16

5.3 EMISSIONS FROM A PLANT CONTROLLED TO MEET A TYPICAL STATE IMPLEMENTATION PLAN.................... 5-16

5.4 TOTAL NATIONWIDE EMISSIONS.................... 5-19

5.5 REFERENCES.................... 5-23

6. EMISSION CONTROL SYSTEMS.................... 6-1

6.1 CONTROL APPROACHES.................... 6-1

TABLE OF CONTENTS (Continued)

Page

6.1.1 Refractory Brick Kilns........................... 6-1

6.1.2 Tar and Pitch Operations......................... 6-3

6.1.3 Fused Cast Refractory Production................. 6-3

6.1.4 Ceramic Fiber Manufacture........................ 6-4

6.2 ALTERNATIVE CONTROL METHODS............................ 6-4

6.3 THE BEST SYSTEM OF CONTROL TECHNOLOGY.................. 6-4

6.4 REFERENCES.. 6-7

7. EMISSION DATA... 7-1

7.1 AVAILABILITY OF DATA.................................... 7-1

7.2 SAMPLE COLLECTION AND ANALYSIS.......................... 7-1

7.3 REFERENCES.. 7-4

8. STATE AND LOCAL REGULATIONS.................................. 8-1

8.1 REFERENCES.. 8-4

APPENDIX A.. A-1

APPENDIX B.. B-1

APPENDIX C.. C-1

LIST OF TABLES

TABLE		Page
3-1	Particulate Emission Levels Based on Various Levels of Control	3-7
4-1	Refractory Classification by Composition	4-3
4-2	Revised and Simplified Classification of Formed Products	4-5
4-3	Unformed Refractory Types	4-7
5-1	Uncontrolled Emission Factors	5-3
5-2	Uncontrolled Gas-Fired Tunnel Kiln Particulate Emission Factor Data	5-6
5-3	Uncontrolled Gas-Fired Tunnel Kiln SO_x Emission Factor Data	5-10
5-4	Uncontrolled Electric Arc Furnace Particulate Emission Factor Data	5-12
5-5	Uncontrolled Tar & Pitch Operations Particulate Emission Factor Data	5-14
5-6	Production Levels	5-17
5-7	Uncontrolled Emissions from Typical Plants	5-18
5-8	Emissions From Plants Controlled to Typical State Regulation	5-20
5-9	Total Uncontrolled Nationwide Emissions Mg/yr (tons/yr)	5-21
5-10	Nationwide Emissions Assuming SIP Control	5-22
6-1	Typical Arc Furnace Baghouse Specifications	6-3
6-2	Best Systems of Control Technology	6-6
7-1	Emission Source Test Data	7-2
8-1	Summary of State Emission Regulations Pertaining to New Sources in the Refractory Industry	8-2
8-2	Estimated National Emission For Uncontrolled and Controlled Sources	8-3

LIST OF FIGURES

FIGURE PAGE

4-1 Distribution of Refractory Plants in the United States 4-10

4-2 Historic Value of Refractory Shipments, Constant 1967 Dollars. 4-12

4-3 Historic Shipments of Refractory Products. 4-13

4-4 Historic Shipments of Refractories Using Tar & Pitch 4-15

4-5 Refractory Manufacturing Flowchart 4-19

4-6 Fired Products Flowsheet 4-21

1. SUMMARY

This report documents a study conducted to assess the need for new source performance standards (NSPS) for the refractory manufacturing industry. These standards would regulate airborne emissions from new point sources involved in the manufacture of refractory products.

This chapter is provided as a general overview of the study.

1.1 INDUSTRY DESCRIPTION

Refractories are defined as any material designed to resist high temperature environments. In industry, refractories are used to line furnaces, boilers, reactors, kilns, steel ladles, and other devices where extremes of temperature, corrosion, and abrasion would destroy any other material. Raw materials used to make refractories are usually ceramic in nature. The most common are clays, bauxite, magnesite, sand, dolomite, chromite, zircon, and various oxides and derivatives of these minerals.

The majority of refractories (59 percent) are sold as bricks and shapes (in this study the term brick will refer to any structural shape). The remainder, termed unformed or specialties, are sold in bulk form. Most unformed products are designed to be mixed with water on the site where they are used and poured into position in an analagous manner to concrete placement.

A new and growing type of refractory product is ceramic fiber. It is similar in manufacture and appearance to mineral wool. It is used as an insulating material on high temperature devices where heat losses are undesirable. Additional markets for ceramic fiber are presently developing.

The steel industry consumes approximately half of all refractories sold in the U.S. Other major consumers are the glass, aluminum, boiler, chemical, and petroleum industries. Continual replacement of refractory linings is common in most applications.

The industry is composed of approximately 250 plants located in 33 states. The plants are concentrated in a tier of states located between New Jersey and Missouri. Total industry annual sales are currently estimated to be approximately $1.2 billion dollars on shipments of over 4.2 Tg (5 million tons). Plants and emissions tend to be highly specialized depending on the type of products manufactured and local raw materials used in manufacture.

Demand for refractory products is not expected to increase in the immediate future. Little, if any overall industry growth is expected in the source category. Growth is anticipated in the unformed segment of the industry, however, emissions from this segment are not covered in this study. The only other refractory product with growth potential is ceramic fiber with indications of 15 percent annual growth.

1.2 PROCESS DESCRIPTION

Refractory manufacture typically breaks down into four phases. These are: raw material processing, forming, firing, and final product processing. Some types of products omit one or more of these phases altogether.

The first phase involves the transformation of raw minerals of irregular size, shape, and moisture content into a stable, uniform, refractory grade material. Operations involved in this phase include crushing, grinding, size classification, drying, and calcining.

The second phase takes appropriate mixtures of raw materials and forms desired shapes. Lower grades of refractories are formed by adding water to the mix to form a wet slurry which is subsequently poured into molds. Medium grades of refractories mix materials and water in a pug mill for subsequent extruding. Higher grades of refractories are shaped by extreme pressure in a brick press. Many variations on these forming processes are used. One important variation is to use tar to hold the brick together allowing skipping of the firing step. Firing occurs in place.

The third phase involves drying and firing of the brick. The most common devices are tunnel dryers and tunnel kilns. Dryers reduce the free moisture content of the brick to prevent excessive cracking and spalling in the kiln. Kilns subject the brick to high temperatures for extended periods of time forming the ceramic bond which gives the brick its desired strength and resistance to high temperatures. Molten cast products melt materials in arc furnaces for subsequent casting into sand molds.

The final phase involves any steps necessary to prepare the product for shipment. Finishing grinding and sandblasting may be required. Products are usually shipped in cartons or on pallets. Some products receive tar impregnation.

Unformed products omit the forming and firing phases. Processed raw materials are mixed and packaged in bags or drums. Firing occurs on site when the vessel they are used in is brought up to working temperature.

Ceramic fiber production is dissimilar to conventional refractory manufacture and similar to mineral wool manufacture. Clay is melted in electric arc furnaces after which it is blown or mechanically formed into long, thin fibers. After fiberization, the fibers are either shipped in bulk or formed into batts, blankets, rolls or other shapes. Ceramic fiber products are excellent high temperature insulators and are very lightweight.

1.3 EMISSIONS

Emissions are examined from the following sources:

- Brick Firing Kilns - Used in the production of fired bricks and shapes,
- Electric Arc Furnaces - Used in the production of fuse cast bricks and shapes,
- Tar and Pitch Operations - Impregnators and tempering ovens used to produce tar bonded and impregnated bricks and shapes,
- Ceramic Fiber Manufacture - Electric arc furnaces, fiberization devices, and tempering ovens used to make and form ceramic fibers.

Other emission sources involved in refractory manufacture are not assessed. Many are small nuisance dust operations which are presently well controlled. Others are covered in other present and proposed NSPS studies.

On a national basis, three emission species are significant; particulates, sulfur oxides, and fluorides. The majority of particulate is generated in brick firing kilns and electric arc furnaces. Sulfur oxides are generated in the combustion of fuel oil, the firing of sulfur containing clays, and the volatilization of plaster used in manufacture of low and medium grades of insulating firebrick. Fluorides are produced in kilns and arc furnaces from the volatilization of fluorine compounds present in clays.

Total controlled national emissions of particulates, sulfur oxides, and fluorides from the source category are estimated to be 1530 Mg/yr (1680 ton/yr), 1610 Mg/yr (1770 ton/yr), and 1100 Mg/yr (1210 ton/yr) respectively. This estimate is based on total production of refractory products from approximately 250 existing plants.

Very little emission data is available. EPA Method 5 was used to determine particulate emissions from a periodic kiln. In stack filters and cascade impactors have been used to determine particulate weight and size in the emissions from a tunnel kiln. The particulate emissions from an electric arc furnace have been tested, however the method was not EPA 5. EPA reference methods for sample collection and analysis are available for all of the emissions which are significant on a national basis.

1.4 CONTROL SYSTEMS

Uncontrolled refractory brick firing kiln emissions are typically below the level required by state regulations. Nearly all tunnel kilns are uncontrolled. One exception is the use of an ionizing wet scrubber installed primarily to reduce opacity. The unusual clay being fired at this plant tends to give rise to high opacity emissions. Particulate control with this device exceeds 85 percent.

Electric arc furnaces used in fuse cast production generate sufficient particulate emissions to require control. Fabric filters are used extensively. Efficiency of the control device is estimated to exceed

99 percent, however, pickup of the particulate laden air above the furnace is a problem. No data is available to estimate this capture efficiency.

Tar and pitch operations emit higher molecular weight organic aerosols. Incineration is the most common control technique. Efficiency is expected to exceed 95 percent. Control may or may not be required depending on local regulations.

Ceramic fiber manufacture generates particulate from electric arc melting, fiberization, and oven curing. Fabric filters or lint cage filters are the most common control although many operations do not require control for existing regulations. Incinerators are occasionally used for control of organic aerosols from curing ovens.

1.5 STATE REGULATIONS

For the most part, particulate regulations are the only state regulations of concern to refractory manufacturers. Most states regulate particulates by a process weight formula. The formulas are fairly uniform from state to state. Opacity is also regulated by most states. A typical allowed opacity is 20 percent.

Assuming state regulations are met, these regulations reduce total national particulate emissions from 4100 Mg/yr (4500 tons/yr) uncontrolled to 1500 Mg/yr (1700 tons/yr) controlled. The majority of this reduction is attained through the control of electric arc furnaces used in fuse cast production. In general, most plants observed during this study appear to be meeting applicable state regulations.

Sulfur oxides and fluorides are generally below levels requiring any control.

1.6 RECOMMENDATIONS

It is not recommended that NSPS be developed for the refractory manufacturing industry at this time for the following reasons:

1. Overall growth in total refractory production is unlikely. A trend toward higher quality refractories which require less frequent replacement will reduce consumption. The only major addition of new sources is expected to occur in the small ceramic fiber segment of the industry.

2. The industry is currently operating below capacity. Considerable demand could be accommodated by further use of existing capacity.

3. Many particulate emission sources in the industry are being addressed in other NSPS source categories.

4. The majority of emission sources examined have indefinite lifespans. Replacement of existing capacity is unlikely.

5. The potential for modification of kilns to fire with coal is very small. No trend toward conversion to coal is apparent.

It is further recommended that drying and calcining of non-metallic minerals used in refractory manufacture be examined in other NSPS studies. One option would be to include this examination in an already proposed clay preparation study.

2. INTRODUCTION

2.1 STUDY OBJECTIVE

The objective of this study is to determine the need for new source performance standards (NSPS) for the refractory manufacturing industry.

2.2 SOURCE CATEGORY DEFINITION

A major problem in the development of this study has been the multitude and diversity of products and processes in the refractory industry. Further complicating the issue is the overlap of several other NSPS projects onto various emission sources in the industry. The Non-Metallic Mineral Processing NSPS and the Metallic Mineral Processing NSPS studies cover the handling, crushing, grinding, conveying, and storage of the majority of raw materials used in refractories. Another NSPS study is being planned to cover clay preparation which would include the drying and calcining of refractory clays.

In an effort to resolve these issues, the industry was examined to determine what processes were indiginous to refractory manufacture or, in other words, what exactly makes refractory manufacture different from other ceramic industries. The answer is heat. Refractories are peculiar in their ability to resist high temperature environments. They acquire this ability by being fired or fused at high temperatures. Thus, this study focuses on heat processes. This meshes well with the Non-Metallic Mineral study as it looks only at non-heat processes.

Several emission sources were identified which do not involve heat and are not covered by other studies. An example is the finish grinding and sandblasting of some products after they leave the firing kiln. Another major source is the bagging of unformed products. Dust control for these sources usually requires large volumes of air to be captured around the process. After pickup in this airflow, the dust is a point source and requires a control device to meet state regulations. Baghouses are used extensively. During this study many of these operations were observed. Pickup was usually good to excellent and baghouses were used without exception.

Fugitive emissions are not examined in this study. Observations of operating plants showed generally low outside fugitive emissions.

Some heat processes are also excluded from this survey. Rotary kilns, shaft kilns, and multiple hearth furnaces are used extensively to dry and calcine raw materials. A proposed NSPS study of clay preparation will cover those sources which process clay. Several other refractory materials are dried and calcined in these devices. These include magnesite, chromite, sand, dolomite, and limestone. However, these materials are heavily used in other industries. Furthermore, many of these sources are located in plants totally separate from refractory plants and supply other users other than refractory manufacturers. For these reasons it is not appropriate for these sources to be included in the source category examined in this study.

The net results of these exclusions is a well defined source category consisting of the following emission sources:

- Brick Firing Kilns,
- Electric Arc Furnaces,
- Tar and Pitch Operations, and
- Ceramic Fiber Manufacture.

The complete process descriptions detailing where these sources are involved in refractory manufacture are in Chapter 4.

2.3 LEGAL REQUIREMENTS

The Clean Air Act (CAA), as amended in 1977, provides authority for the U.S. Environmental Protection Agency (EPA) to control discharges of airborne pollutants. The CAA contains several regulatory and enforcement options for control of airborne emissions from stationary sources. Section 111 of the CAA calls for issuance of standards of performance for new, modified or reconstructed sources which may contribute significantly to air pollution. The standards must be based on the best demonstrated control technology. Economic, energy and non-air environmental impacts of control technology must be considered in the development of standards.

To determine which processes and pollutants, if any, should be regulated by national NSPS, the following information has been provided in this survey:

- description of facilities included in source category,
- number and location of facilities,
- past and current volumes of production and sales, products, and product uses,
- past and future growth trends in the industry,
- description of the processing operations and identification of emission sources,
- characterization of emissions from processing operations,
- estimation of national emissions from source category,
- identification and description of control techniques currently used in the industry,
- identification of the "best systems" of control,
- description of state regulations applicable to the source category, and
- preferred methods of sampling and analyzing the pollutants.

2.4 APPROACH

Several information sources were used in the development of this report. Initially, a literature search was conducted to gather background material on the refractory industry. This material provided a basis for further information gathering in the form of telephone and letter contacts with manufacturers engaged in the production of refractory products, regional offices of EPA, and state and local air pollution control agencies. The trade association for the industry, The Refractory Institute, was also contacted. Visits were made to six refractory plants.

A list of people helpful in this study is given in Appendix C.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

3.1.1 General

The refractory industry manufactures a wide variety of high temperature materials used to line furnaces, boilers, reactors, kilns, ladles, and other high temperature equipment. The majority of refractories are used by the steel industry. Bricks and shapes constitute the majority of production at 59 percent of shipments; unformed products constitute the remainder.

The industry is large by any standard. Over 250 plants are believed to be operating in the U.S. producing over 4.5 Tg (5 million tons) valued at over 1.2 billion dollars annually.

Raw materials used in refractory manufacture are generally ceramic in nature. Clays are the most common raw material, however, the industry uses a wide variety of other minerals.

Refractories are a vital part of virtually every major heavy industrial process. Three factors are mainly responsible for refractories being considered a critical industry in the economy. First, refractories play a role in the production of nearly every processed raw material including steel, glass, copper, aluminum, zinc, and others. In short, the production of these materials is impossible without continued supplies of refractory products. Second, refractory production is susceptible to cutoffs in foreign minerals, particularly bauxite and chromite. Finally, refractories are extremely energy intensive. Rapidly increasing energy costs hit this industry particularly hard. Curtailments of fossil fuel sources have shut down production in the past and are likely to do so again in the future.

Refractory plants and refractory products in general are highly specialized. The number of types of products produced is estimated to be over 25,000. This is in contrast to the concentration of refractory consumers in the steel industry which uses over 50 percent of present production. The combination of diversified production and concentrated market cause refractory producers problems in maintaining uniform production schedules. Because products are unstandardized, inventories cannot be allowed to accumulate during periods when orders are slack. Production tends to run in cycles reflecting the general state of the steel industry and the economy in general. Production has still not recovered from drastic production cuts in the mid 1970's. This downturn was caused by the double blow of an economic recession coupled to severe fuel shortages.

Raw material usage is also highly unstandardized. Many refractory products are inherently low in value and are sold in a competitive market which causes plants to be located in areas with specific combinations of readily available local minerals and an adjacent consumer. As a consequence, emission sources and emissions in general vary tremendously from plant to plant.

3.1.2. Source Category Definition

The following emission sources are defined as the source category and are examined in this report:

- Brick Firing Kilns,
- Electric Arc Furnaces (used in fuse cast production),
- Tar and Pitch Operations (impregnation and tempering ovens), and
- Ceramic Fiber Manufacture (electric arc furnaces used to melt clay, blowchambers, and curing ovens).

Other significant emission sources involved in refractory manufacture are not examined. These sources are excluded because of other NSPS studies, presently being conducted or proposed, which will examine these sources. Additionally, a number of sources are not examined because the process and material generating the emission are widely used in other industries. These sources are best examined under less industry specific source category definitions.

A more complete discussion of the source category definition is contained in Chapter 2.

3.1.3 Growth Trends

The industry is still undergoing a variety of changes begun in the early 1960's. The following outlines the major trends identified during this study.

The most important trend, from an industry growth standpoint, is the shift toward higher quality refractories in lieu of lower grades of refractories. These higher grade products require less frequent replacement than lower grade products. This change can be noted from the long term trend of dollar sales of products as opposed to the long term trend in actual volume of shipments. Constant dollar (adjusted for inflation) sales of refractories generally show strong growth in the past ten years while the actual volume of shipments show no growth over the same period.

A second important trend is the shift toward unformed refractories as opposed to conventional bricks and shapes. Unformed products are usually sold as dry granular mixes designed to have water added or are sold in a plastic state with water previously added. Except for raw material calcining, no firing of the product has occurred at the refractory plant. Instead, firing is accomplished insitu as the vessel they are placed in is brought up to operating temperature. Unformed refractories offer considerable fuel savings in manufacture over formed products. They also allow customers greater freedom and flexibility in use and placement.

Another trend is the shift toward basic products and away from silica products. Basic refractories are noted for extreme refractoriness and excellent resistance to decay in high pH environments. The primary impetus for this shift has been the conversion of steelmaking operations away from open hearth furnaces and toward basic oxygen furnaces (BOF's). As basic products have been produced in larger and larger quantities, their price has become competitive to the point where they are now economical for a variety of applications apart from BOF's.

A recent development has been the emergence of the ceramic fiber product line. These refractories are very similar in manufacture and appearance to mineral wool products. Clays are the raw material as opposed to rock and slag in mineral wool production. The manufacturing processes are very similar with one exception. Electric arc furnaces are used to melt clay for ceramic fiber production; cupolas are the primary method of melting rock and slag in mineral wool manufacture.

Ceramic fiber is the only refractory product with emission sources examined in this report which is expected to experience overall growth in production capacity. However, ceramic fiber represents less than 1% of present refractory production. Thus, the potential number of new sources is very small.

Other than ceramic fiber, little if any overall growth in new emission sources is expected. A very small number of consolidations of existing sources are possible.

3.1.4 Emissions and Controls

Two sources are responsible for the majority of particulate emissions. These are brick firing kilns and electric arc furnaces used in fuse cast manufacture.

Most kilns emit low levels of particulates. The particulate emission factor is estimated to be .5 kg/Mg (1.0 lb/ton) which results in an emission of approximately, 19.9 Mg/yr (21.9 tons/yr) for a moderate to large uncontrolled kiln. Kilns are not usually required to use control devices to meet state regulations. Only one refractory brick kiln in the U.S. is known to be operating a control device. This device is a multiple stage scrubber installed to reduce opacity. On a national basis, refractory brick kilns can be considered uncontrolled.

Electric arc furnaces emit relatively high levels of particulates. The uncontrolled emission factor is estimated to be 25 kg/Mg (50 lb/ton) which results in an emission of approximately 284 Mg/yr (312 tons/yr) for a moderate to large uncontrolled arc furnace. This level of emission has necessitated the use of control devices to meet state emission regulations. Baghouses are the usual method of control. Capture of the emissions as they leave the furnace is a problem, however.

The net results of these factors is approximate parity between particulate emissions from an uncontrolled kiln and an arc furnace controlled to meet state regulations at 20 Mg/yr (22 ton/yr). However, since kilns outnumber arc furnaces by a wide margin, total national emissions are much greater for kilns at 1145 Mg/yr (1260 ton/yr) versus 251 Mg/yr (276 tons/yr) for arc furnaces.

Tar and pitch operations generate organic particulate emissions during impregnation and tempering processes. No data is available to estimate the current level of control, however, regulations do not typically require any control device. Uncontrolled emissions are estimated at 88.3 Mg/year (97.1 tons/yr) nationwide.

Ceramic fiber manufacture generates particulates during melting of the clay feedstock, during the fiber formation process, and in oven curing processes. Low levels of hydrocarbon emissions are also generated during the later two processes. State regulations may require some particulate control of the melting and fiber formation processes. Present national emissions from all ceramic fiber processes are estimated at 120 Mg/yr (132 tons/yr).

The only major sources of sulfur oxides in the source category are firing kilns. The majority of these emissions result from the burning of sulfur bearing fuel oil. However, the use of plaster in the manufacture of insulating fire brick also contributes relatively large amounts of sulfur oxides. Since this production is usually concentrated in a few plants the local impact of this emission may be quite substantial. National sulfur oxide emissions are estimated to be 1609 Mg/yr (1770 tons/yr).

Fluoride emissions are generated in the firing and melting of minerals containing fluorine compounds. The emission level of fluoride can be expected to be site and material specific. The national fluoride emission production is estimated to be 1100 Mg/yr (1210 tons/yr) from the source category.

In general, kilns seldom emit enough particulate to cause a visible emission problem. A major exception are kilns firing ladle brick. The clay used in ladle brick produces a submicron particulate fume which is highly reflective.

As presently controlled, no other processes in the source category are significant sources of visible emissions.

3.1.5 NSPS Emission Reduction Potential

In order to assess the environmental impact of a potential NSPS regulation, an estimate of the particulate emission reduction potential for each emission source under consideration is made. This estimate is presented in Table 3-1. Uncontrolled particulate emissions are estimated using uncontrolled emission factors developed in Chapter 5. Present controlled emissions are based on the allowed emissions from sources meeting a typical state regulation. State regulations are reviewed in Chapter 8. The NSPS control level is estimated assuming use of the best control technology available for each emission source. Control technologies are reviewed in Chapter 6.

Table 3-1 addresses reductions in particulate emissions only. Data is insufficient to assess the potential reduction for sulfur oxides and fluorides. Both emissions are very site specific depending on the raw refractory material. The emission reduction potential would depend on the location of the new source.

Concerning the nationwide reduction in particulate emissions through implementation of NSPS, the low growth potential of the present refractory industry precludes a major reduction. No overall increase in refractory production is anticipated through 1985. Furthermore, present production is approximately 85 percent of peak production levels reached in 1974. Thus, approximately 15 percent unused long term capacity is available without expansion or construction of new emission sources.

The only potential for new emission sources lies in the replacement of existing emission sources, the conversion of existing production to other types of production, or expansion into the very small ceramic fiber market. Replacement of existing kilns and furnaces is unlikely since this equipment is reported to have long, indefinite lifespans. Production conversion is possible and would probably occur in the basic product or unformed product lines. The number of new basic, unformed, or ceramic fiber plants which would be built in the next five years,

TABLE 3-1. PARTICULATE EMISSION LEVELS BASED ON VARIOUS LEVELS OF CONTROL Mg/yr (ton/yr)

	Firing Kiln		Electric Arc Furnace		Ceramic Fiber Plant	
Uncontrolled Emissions	19.9	(21.9)	284	(312)	36.9	(40.6)
Present Controlled Emissions	19.9	(21.9)	18.5	(20.3)	20.2	(22.2)
NSPS Controlled Emissions	3.0	(3.3)	14.2	(15.6)	1.8	(2.0)
NSPS Reduction Potential	16.9	(18.6)	4.3	(4.7)	18.4	(20.2)

Notes: 1. Based on following production rates
Kilns - 5 tons/hr and 43,800 tons/yr
Arc Furnace - 2 tons/hr and 12,480 tons/yr
Fiber -.5 tons/hr and 3,120 tons/yr

2. Present control based on typical state regulation taken as
$E = 4.1 P^{.67}$ (see Chapters 5 & 8)

3. NSPS control based on following overall efficiencies
Kilns - 85% reduction
Arc Furnaces - 95% reduction
Fiber - 95% reduction

however, is small with approximately one plant estimated to be built. The possibility of major industry expansion is considered remote.

In summary, the particulate emission reduction potential of NSPS is small due to the following factors. First, the larger particulate emission sources such as crushing and grinding of clays are currently under NSPS regulatory review in other studies. Second, the emission reduction possible through a refractory NSPS is small due to generally low uncontrolled emissions or a high level of current control. Finally, the growth potential in new emission sources is small with only one new plant likely to be built during the next five years.

3.2 RECOMMENDATIONS

It is not recommended that NSPS be developed for the source category examined in this report. The reasons for this recommendation are:

1. The industry shows little overall growth potential. Long term trends indicate no overall increase in total refractory shipments is likely by 1985. Furthermore, continued advances in refractory technology are expected to result in higher quality products. These products will require less frequent replacement and will reduce overall consumption. Any new sources possible will be the result of consolidation of existing facilities and expansion in the small ceramic fiber segment of the industry. Any consolidation is likely to be very small.

2. The industry has still not recovered from production cuts in the mid-1970's. Thus, considerable unused capacity is available to meet demand.

3. Several major particulate emission sources in the refractory industry, such as crushing and grinding, are currently under NSPS regulatory review in other source categories. The remaining emission sources are either small particulate emitters or are currently well controlled.

4. Emission sources involved in refractory manufacture tend to have indefinite lifespans. Kilns are rebuilt in small sections and arc furnaces have few components subject to wear or deteriorate. Replacement of existing capacity is unlikely.

5. The potential for modification of kilns to fire with coal is very small. Industries experience with coal firing has shown serious technological problems which will constrain the use of coal. Additionally only a small part of the industry fires at a low enough temperature to make coal firing feasible.

It is further recommended that consideration be given to expanding a proposed source category survey of clay preparation (primarily calcining and drying) to include other major non-metallic mineral heat processing. This study identifies magnesite, dolomite, and chromite drying and calcining as potentially significant emission sources which should be examined. If expansion of this clay preparation study is deemed inappropriate, it is recommended these sources be examined under a separate study.

4. DESCRIPTION OF INDUSTRY

The refractories industry in the United States is quite diversified. It is estimated that over 25,000 different refractory products are produced by over 250 manufacturers located in 33 states.[1] While many of these products are quite similar, the industry remains generally unstandardized with each manufacturer producing unique products to suit individual customer requirements. This diversification complicates a source category emission assessment.

This chapter is provided to give the reader a general overview of the industry with respect to its definition, classification, growth potential, and processes. Because of the multitude of products involved, simplifications are made in light of the general nature of the study. The results may neglect to mention some products and processes, however, the majority of the industry is covered.

4.1 SOURCE CATEGORY DESCRIPTION

4.1.1 Definition

Refractories are defined, in the most general sense, as any material designed to maintain structural integrity in high temperature environments. In actuality, refractories are also called upon to resist extremes of physical wear and corrosion. They are used to line furnaces, boilers, reactors, kilns, steel ladles and other vessels where extremes of temperature, pH, and abrasion would destroy any other material.

Refractories are generally composed of non-metallic ceramic materials such as oxides of aluminum (alumina - Al_2O_3), silicon (silica - SiO_2), magnesium (magnesia - MgO), and other elements. In addition, a variety of other materials may be used to give the refractory its desired properties (called refractoriness). The raw minerals from which refractories are produced include clay, bauxite, kyanite, magnesite, chromite, sand, dolomite, zircon and many others. Additives are also used to facilitate production or to give the product a special property desired for a particular application.

4.1.2 Classification

The refractory industry is given two separate and mutually exclusive codes in the U.S. Department of Commerce's Standard Industrial Classification (SIC) system.[2]

- SIC 3255 - Clay Refractories
- SIC 3297 - Non-Clay Refractories

The distinction between the two classes may be quite insignificant from the manufacturers viewpoint. For example, a refractory brick with 86 percent alumina content is classified as a non-clay refractory while one with 84 percent alumina content is classified as a clay refractory. The only difference involved in manufacture is a slight readjustment of the raw material mix. But in principle, SIC 3255 classifies a product whose raw material is primarily clay while SIC 3297 covers products with other primary raw materials. A basic refractory composed primarily of magnesite is a good example of a non-clay refractory.

The present terminology in use by the industry differentiates products by names which may be based on material composition, form, or intended use. For example, the term ladle brick refers to a type of refractory used to line pouring ladles in the steel industry, whereas high-alumina refers to a refractory with a percentage of alumina which falls into a specific range. Ladle brick may be high-alumina yet industry people generally consider high-alumina brick and ladle brick as two separate categories intended for two different applications.

A variety of classification schemes have been proposed which categorize the various products according to composition. A typical scheme is shown in Table 4-1. This classification has reduced the range of products by classifying a wide range of products under one heading. As can be seen, the variation in material composition is considerable.

Refractories can also be classified by the form of the finished product. The historic nucleus of the refractory industry is the refractory brick. The term brick is rather misleading, however, as customers require a myriad of different shapes to build walls, arches, curved surfaces, and to conform to other irregular surfaces. Brick, as used in this report, identifies any structural shape. Formed products are all

TABLE 4-1 REFRACTORY CLASSIFICATION BY COMPOSITION

Refractories	Maximum useful temperature, °F[1]	Major chemical constituents	Raw materials	Typical applications (partial listing)
Clay:				
Low duty..............	2,[illegible]30	SiO_2-Al_2O_3	Raw and calcined fire clay.	Backup brick and low-temperature working linings.
Intermediate duty.....	3,000	SiO_2-Al_2O_3	..........do..........................	Boilers, heat treating furnaces, incinerators.
High duty..............	3,150	SiO_2-Al_2O_3	..........do..........................	Rotary kiln hoods, boilers, cupolas, combustion chambers.
Superduty..............	3,200	SiO_2-Al_2O_3	..........do..........................	Electric furnace roofs, aluminum furnaces, steel ladles, checkers, kiln linings.
High-burned superduty.	3,200	SiO_2-Al_2O_3	..........do..........................	Checkers, aluminum furnaces, iron blast furnaces.
Insulating.............	3,000	SiO_2-Al_2O_3	Raw and calcined fire clay plus additives.	Boilers, refinery heaters, annealing furnaces, and wherever insulation is a consideration.
Acid-resistant (type H).	3,000	SiO_2-Al_2O_3	Raw and calcined fire clay.	Chemical processing, applications requiring resistance to acids and alkalis.
Semisilica.............	3,000	SiO_2-Al_2O_3	Sand and fire clay mixtures.	Good load bearing properties. Better spall resistance than silica brick. Boiler piers, stove sidewalls.
High alumina (50-85 percent Al_2O_3).	3,300	Al_2O_3-SiO_2	Fire clay, bauxite, diaspore, alumina.	Electric furnaces, sludge burners, lead burners, lead furnaces, cement kilns, lime kilns, aluminum furnaces.
Nonclay:				
Extra-high alumina (90.0-99.5 percent Al_2O_3).	Up to 3,650.	Al_2O_3	Alumina (high-purity).	For uses where higher service requirements are indicated. Used in glass melting and other furnaces.
Silica:				
Standard.............	3,000	SiO_2 (largely)-CaO	Ganister-lime.	Coke ovens, glass tanks, copper reverberatory furnaces.
Superduty............	3,100	SiO_2 (largely)-CaO	..........do..........................	High-temperature zones of tunnel kilns and in place of standard silica when conditions warrant, electric and steelmaking furnaces.
Alumina-silica: Mullite.	3,300	Al_2O_3-SiO_2	Kyanite, sillimanite, bauxite, sintered or fused mixtures of aluminous and siliceous materials.	Glass tanks, crucibles, ferrous and nonferrous metal industries for special uses, electric arc furnace roofs, blast furnace stoves.
Magnesia and chromite:				
Magnesite............	3,600	MgO (largely)	Magnesite or magnesia plus binding agents.	Glass furnace regenerators, electric and open hearth bottoms, walls and roofs, copper furnaces, cement kilns, high-temperature chemical processes, basic oxygen steelmaking converters.
Magnesite-chrome....	3,200	MgO-Cr_2O_3	Magnesite and chromite plus special additives.	Open hearth walls and roofs, electric furnace walls, cement kilns, glass tank regenerators, copper furnaces.
Chrome...............	2,800	Cr_2O_3	Chromite plus special additives.	Steel furnaces, copper furnaces, soaking pits, reheat furnaces, neutral course between magnesite and silica refractories.
Chrome-magnesite....	3,200	Cr_2O_3-MgO	Chromite and magnesite plus special additives.	Open hearth roofs, walls, and bottoms; electric furnace walls, glass furnace regenerators, nonferrous metallurgical furnaces.
Dolomitic: Dolomite-magnesite.	Varies--over 3,300	MgO-CaO	Dolomite and magnesite plus binders.	As the tar-bonded, high-dolomitic material mainly in the basic oxygen steelmaking converter, cement kiln burning zones.
Carbonaceous:				
Carbon...............	6,000+ under reducing conditions.	C	Petroleum coke, low-ash metallurgical coke, tar, pitch, and other additives.	Blast furnace hearth, bosh, and stack, refractory linings and cathodes of aluminum potlines, furnaces for production of ferroalloys, calcium carbide, phosphorous, phosphoric acid. Ferroalloy casting molds. Highly resistant to thermal shock, high hot strength, but attacked by air, water, and carbon dioxide at low temperatures.
Graphite.............	...do.............	C	Natural and artificial graphite plus binders and additives.	Crucibles and ladle stopper heads, retorts and other shapes.
Special types: Various.	To 5,000 or higher, under special conditions.	Varies.	Especially produced from selected materials: Metal oxides or their mixtures such as alumina, chromia, lime, magnesia, and zirconia; also various carbides, nitrides, silicides, borides, and other materials.	Very high temperatures, unusual corrosive conditions, unusual atmospheres and abrasive conditions: Reaction engines, heat exchangers, glass tank pavers, atomic reactors, and aerospace applications.

---

[1] May vary, depending on environmental and operating conditions.

Reference 39

characterized in that they exist as individual structural units.

Unformed products are sold as continuous mixtures of refractory materials which may be poured, molded, rammed, gunned, or placed into position by other means. The earliest unformed products were primarily refractory mortars used to place bricks and form continuous monolithic structures. Unformed refractories are now manufactured in a variety of types and are displacing increasing numbers of formed refractory products. Their principle advantage lies in that they are not fired at the refractory plant except for the calcining of raw materials. Instead the ceramic bond between the refractory grains is achieved as the vessel in which they are placed is brought up to temperature in its first heat. In other words, firing takes place on site. Energy saved by avoiding the firing step at the refractory plant gives unformed products an economic advantage.

In order to facilitate discussion about various refractory types, Table 4-2 presents a revised classification system which groups formed refractories into large blocks of products. This system differentiates between products based both on composition and intended use. Table 4-3 outlines the various types of unformed refractories. No raw materials are given in this table. Unformed products may be produced in virtually any formulation for any application.

One new class of refractory products, ceramic fiber, is not amenable to classification as either a formed or unformed product. Ceramic fibers are similar to mineral wool or fiberglass and use essentially the same basic production process as mineral wool. They may be sold in bags as bulk fibers or may be formed into boards, batts, or other products. Ceramic fiber refractories are used to insulate high temperature vessels and thus reduce heat losses. The manufacturing processes and emissions are entirely different from other refractories. Therefore, ceramic fibers are considered separate from formed and unformed products in this report.

Many exotic products have not been mentioned. Examples are silicon-carbide and graphite refractories. Exotics have highly specialized uses

TABLE 4-2 REVISED AND SIMPLIFIED CLASSIFICATION OF FORMED PRODUCTS

Refractory Type	Major Raw Materials	Usage	Comments
Fireclay	Fireclays additives	Non-extreme conditions without high or low pH's.	Most fireclay products are made simply by the mining, crushing, forming, and firing of fireclays. This segment of the market has steadily declined in the past two decades in favor of tougher high-alumina products.
High-alumina, Xtra-High Alumina	Fireclays, bauxite, diaspore, refined alumina	Nearly all applications where a tougher lining is needed than can be made with fireclays. Resistance to basic solution is still poor.	The production of these refractories is similar to straight fireclay. Materials are of higher purity. These products have experienced strong growth as they displaced fireclays.
Insulating Firebrick (IFB)	Fireclay, sawdust or perlite added in production for low & medium temperature.	Usually used to back up a tougher, denser working lining. Resistance to abrasion is poor, especially in lower grades.	Sawdust burns inside the brick during firing to create a light porous brick. Perlite expands when heated. Ceramic fiber is beginning to displace IFB.
Ladle (& pouring pit)	Bloating clays	Used almost exclusively to line ladles in the steel industry. Since conditions are severe, consumption is considerable.	The bloating clays expand permanently when first heated in service. This wedges the bricks together to form a tight monolithic lining.

TABLE 4-2 Continued

Refractory Type	Major Raw Materials	Usage	Comments
Basic	Magnesite (Periclase), chromite, dolomite. Tar sometimes used as binder.	Used primarily in steel industry in basic oxygen process. Excellent resistance to high pH environments. Extremely dense, high-duty refractory. Fairly expensive.	Basic products have ridden the BOP conversion. These are some of the toughest refractories used in particularly bad environments.
Alumina-Silica, Silica, Mullite, Zircon	Kyanite, sillimanite, sand, bauxite, zircon	Excellent structural strength. Used extensively in glass industry. Less steel industry use than other products.	This group of products includes a wide variety of formulations and most fuse cast production.
Exotics	All previous entries plus graphite, carbide, forsterite and others.	Special extreme conditions.	Production is small and highly specialized. Fuse casting is used extensively.

TABLE 4-3 UNFORMED REFRACTORY TYPES

Castables	Also called refractory concretes, castables are dry granular refractory mixes designed to be mixed on site with water to be poured, pumped, or troweled into position. They may be used for patch repair as well as complete furnace linings.
Gunning Mixes	Gunning mixes are essentially similar to castables except that they must be able to be blown into position by air pressure through a lance or nozzle. They are usually designed to stick to surfaces as they are applied. They are often used in furnaces for quick repairs while the vessel is still hot.
Mortars	Refractory mortars are usually similar in composition to the brick they are used with. Mortars compose the binder between bricks and shapes to form a complete monolithic structure.
Plastics	Plastics differ from the previous entries in that water is added during production resulting in a plastic material similar in feel and appearance to modeling clay. Plastics may be troweled into place or blocks of the material may be stacked to form complete walls and linings inside furnaces.

such as nose cones on missiles designed to resist the heat of atmossphperic reentry. In general, emissions from this segment of the industry are negligible due to:

- Small Production - Rough estimates indicate less than 1 percent of refractory shipments,[3]
- Refined Raw Materials - Impurities in the raw materials going into exotics cannot be tolerated due to degradation of the refractoriness. Materials tend to be extremely pure, stable, and inert. Most arrive at the plant refined or preprocessed, and
- Extreme Firing Temperatures - Because the use of natural gas or electricity for all heat processing is required, process fuel emissions are neglibible.

This discussion of classification would not be complete without mentioning the problems associated with the term "castable refractories." The correct definition of a castable refractory, as recognized throughout the industry and as used by the Department of Commerce, is a refractory concrete usually mixed with water on site. It is then poured into forms or molds in much the same way as concrete would be placed.

Other studies have assumed castable refractories to be a variety of totally different products. For example, EPA document AP-42[4] uses the term to describe fuse or molten cast products.

The misunderstanding has caused problems when production data for true castables was used with emission factors developed for fuse cast products. This error has resulted in serious overestimation of emissions in past studies.[5]

4.1.3 Extent of Production Facilities

Data provided by The Refractory Institute indicates that there are approximately 270 plants producing refractory products in the United States.[6] Their information claims virtually complete coverage of the industry. Other sources indicate that the actual number of operating plants may be lower; perhaps around 240.[7] Most sources seem to be in agreement that the actual number of companies operating these plants number around 100.[8] Appendices A and B list the larger producers in SIC's 3255 and 3297 respectively. The ranking was done by using the dollar value of product sales.

Geographically, refractory plants are concentrated in the tier of states running between New Jersey and Missouri. Pennsylvania and Ohio alone account for 43.6 perdent of the plants in the U.S.[9] Figure 4-1 illustrates the distribution of plants in the country. The concentration of plants is attributable to two major factors. First, the steel industry consumes approximately 50 percent of the output of the industry.[10] The plants tend to be located adjacent to steel producing areas in Pennsylvania, Ohio, and Illinois. Second, one of the major raw materials for refractories is clay. Certain clay formations in Missouri, Georgia, and Pennsylvania have particularly desirable properties.

The industry is still undergoing changes started in the 1960's. During this period, larger concerns began to consolidate smaller manufacturers at a rapid pace. Large corporations now control the majority of the industry. The largest refractory producer operates 17 plants across the U.S.[11] Furthermore, these larger corporations are increasingly becoming subsidiaries of large conglomerate corporations. In many cases, the same conglomerate will own the refractory company and the customers using the refractories produced. Another trend has been the gradual decline in silica refractory plants located primarily in Pennsylvania. These plants were abandoned as the steel industry switched over to the basic oxygen process (BOP) for steelmaking which uses basic rather than silica products.

Total employment in the refractory industry numbers approximately 20,000.[12] Dollar sales in 1977 totalled over 1.2 billion dollars for total refractory shipments roughly estimated to be well over 5 million tons.[13] Present production is believed to be roughly equivalent.

4.1.4 Special Industry Considerations

Two aspects of the industry deserve special attention. First, the refractory industry occupies a uniquely central role in the American production system because of the vital role it plays in the production

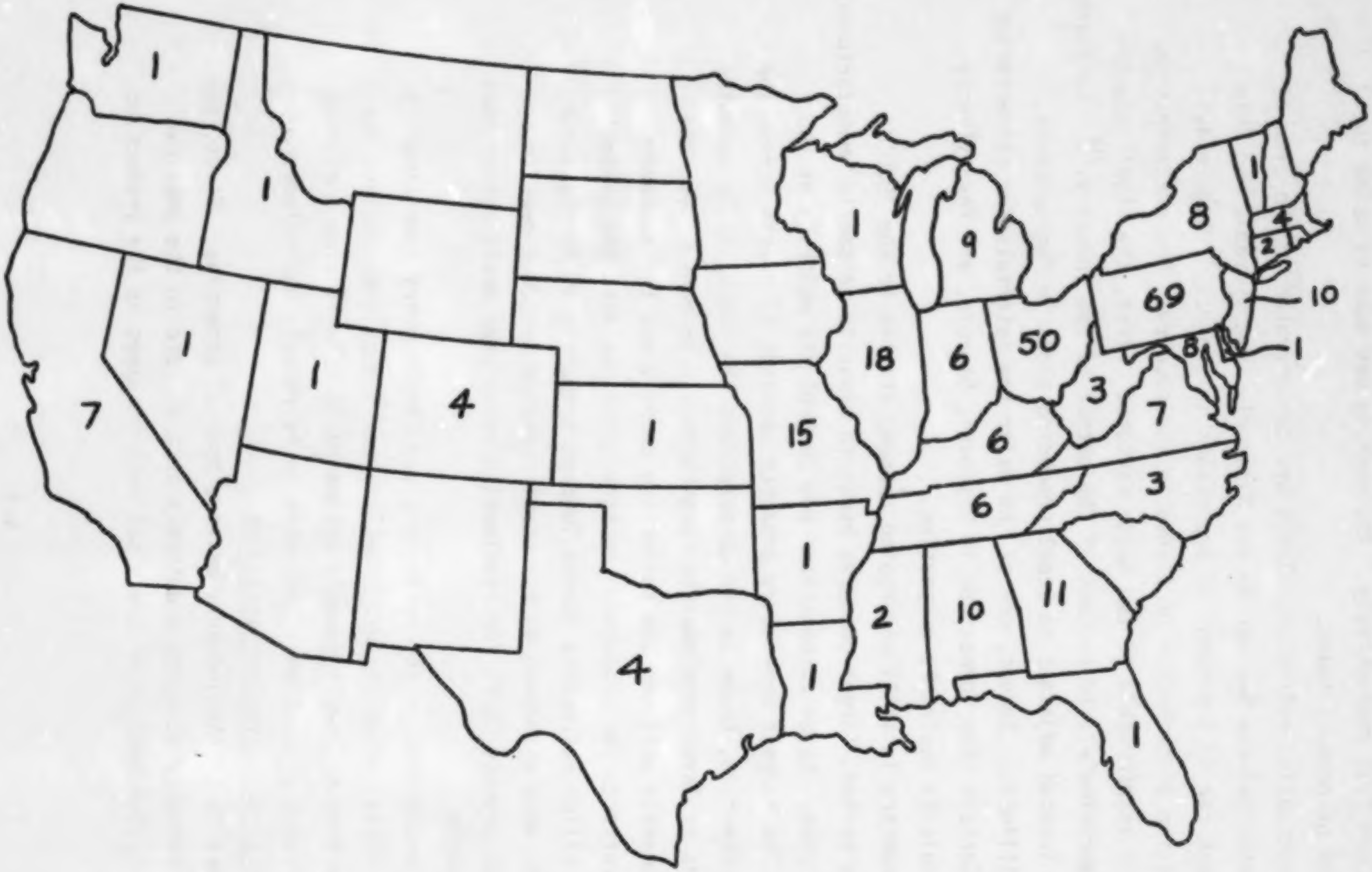

1
1
1
1
7
4
1
15
1
1
4
1
2
18
9
6
50
6
6
10
11
3
3
7
1
8
1
4
2
69
10
8
1

FIGURE 4-1 DISTRIBUTION OF REFRACTORY PLANTS IN THE UNITED STATES

Reference 40

of the majority of industrial raw materials. A study by Battelle Columbus Labs showed that each dollar of refractory output supports \$1266 of Gross Nation Product (GNP) in 1970.[14] This figure ranks refractories among the top ten industries in the U.S. based on leverage ratios, higher than steel, glass, and cement.

Second, the industry is presently beset with a serious problem in spiraling energy costs. Refractories are extremely energy intensive. For example, one of the most energy intensive refractories now being produced is a basic brick composed primarily of magnesite. Fired in the most efficient manner possible with today's technology (a tunnel kiln), the energy content of the finished product is estimated to be 19.2 MJ/kg (8240 BTU/1b).[15] To put this energy usage in perspective, approximately 2.4 cubic meters (85 cubic feet) of natural gas are required to produce one standard nine inch brick. Refractory manufacture approaches the energy usage in such traditionally energy intensive industries as aluminum, steel, and copper. Furthermore, the industry is nearly totally dependent on fossil fuels.

4.2 INDUSTRIAL PRODUCTION TRENDS

This section discusses historical and projected production trends. Section 4.2.1 presents historical production patterns for segments of the refractory industry. Section 4.2.2 projects future production trends for different products in the industry.

4.2.1 Historical Patterns

As can be seen in Figure 4-2, until the first quarter of 1979, the value of refractory shipments, in constant 1967 dollars, has not exceeded a peak achieved in 1974. After a two or three year period well below the 1974 peak the value of shipments started to recover. The nonclay refractories recovered somewhat earlier and stronger than the clay refractories. Prior to 1974 the industry had shown substantial growth in the 1955 to 1965 period[16] but leveled off until the early 1970s when sales started to increase to the 1974 peak.

As can be seen in Figure 4-3, the quantity of refractory products shipped has, with the exception of the unformed products, not been

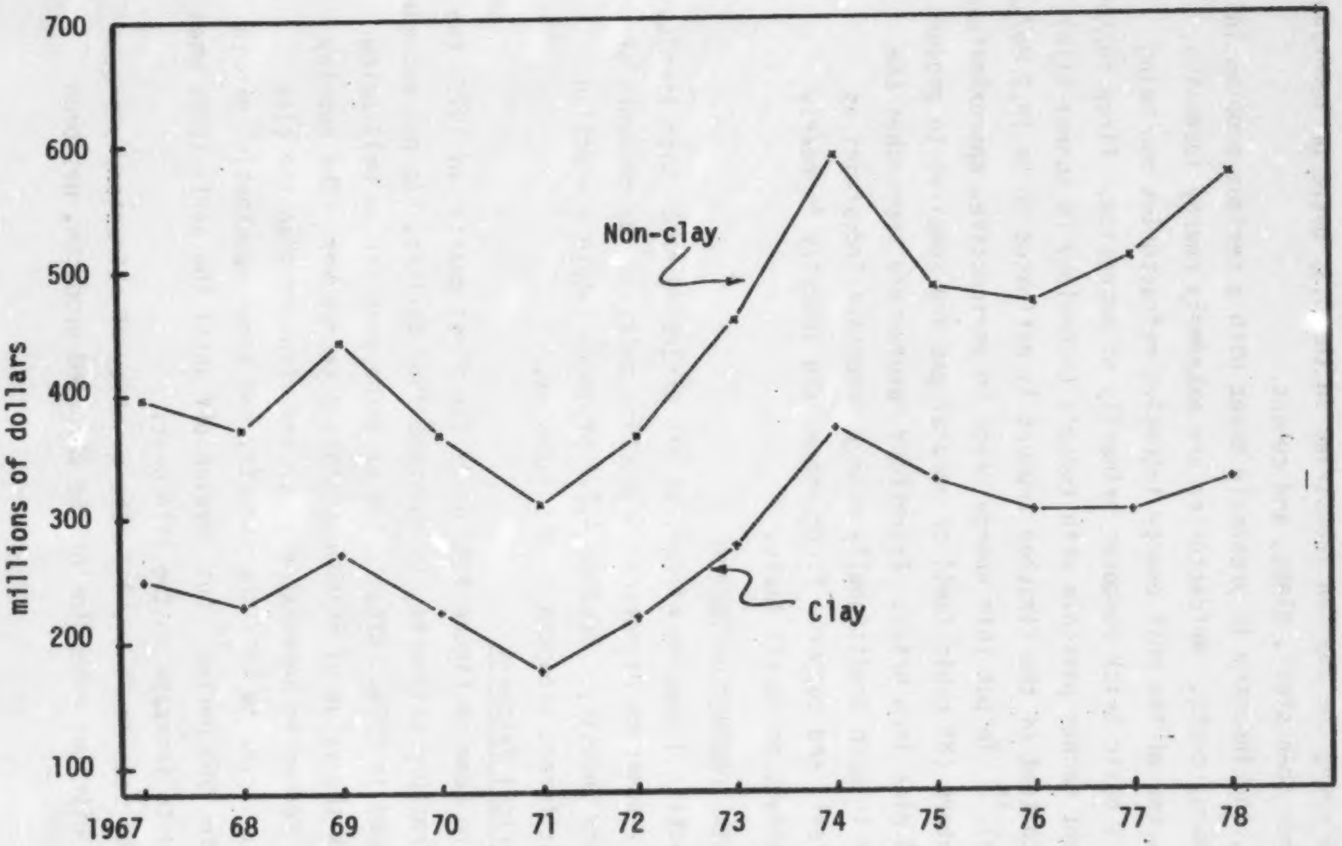


FIGURE 4-2 HISTORIC VALUE OF REFRACTORY SHIPMENTS, CONSTANT 1967 DOLLARS

Reference 41

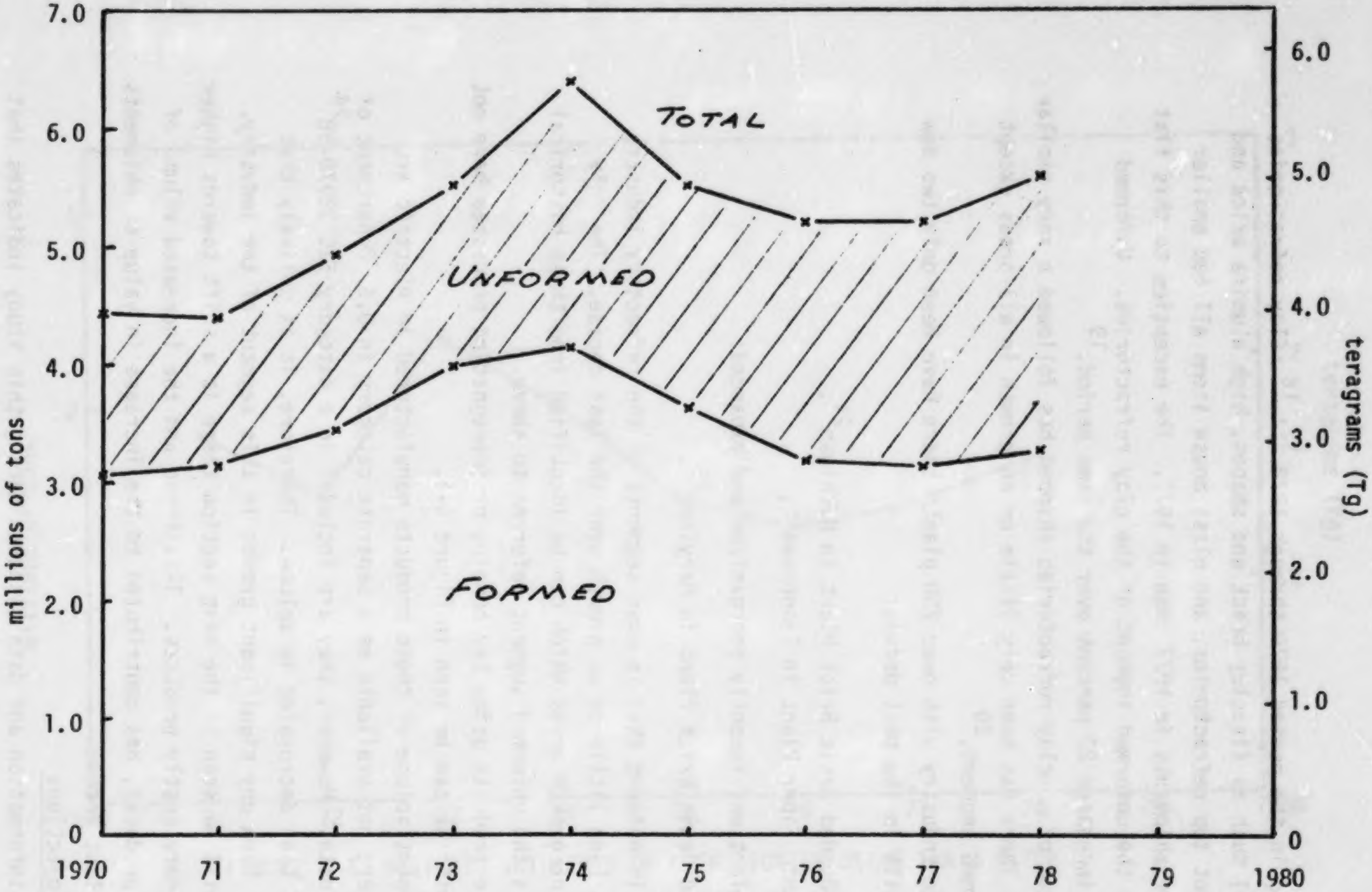


FIGURE 4-3 HISTORIC SHIPMENTS OF REFRACTORY PRODUCTS

Production data compiled using Department of Commerce data and average densities for each product line.[42]

increasing in the period 1970 through 1978.[17, 18] Clay refractories (SIC 3255) such as fireclay brick and shapes, high alumina brick and shapes, hot top refractories, and glass house items all had smaller volumes of shipments in 1977 than in 1972. The exception to this flat trend was the unformed segment of the clay refractories. Unformed products increased 23 percent over the same period.[19]

Volume of nonclay refractories shipped has followed a very similar pattern. There has been very little or no growth in all areas except the unformed segment.[20]

In an industry with over 250 plants there have been only two new plants built in the past decade:

- Tar-Bonded Basic Brick Plant in Michigan[21],
- Ceramic Fiber Plant in Tennessee[22],

and one plant was recently reorganized and expanded:

- Fired Basic Brick Plant in Maryland[23].

Thus, it is evident that in most segments of the refractory industry there has been little or no growth over the last decade. The only significant growth areas which can be identified from these historical records is the unformed segment referred to above.

Those products using tar bonding or impregnating processes have not been growing as can be seen in Figure 4-4.

Shipment volume of those products manufactured in electric arc furnaces are not available as a separate category in U.S. Department of Commerce data. However, they are included in a category SIC 32970-58[24] which has been decreasing in volume. Therefore, it is unlikely that there has been any significant growth in this segment of the industry.

As will be seen in the next section there is a shift towards higher quality, more costly products. This trend and the increased volume of unformed products, has contributed to the increase in value of shipments over the last decade.

4.2.2 Projections

The information and data gathered during this study indicates that

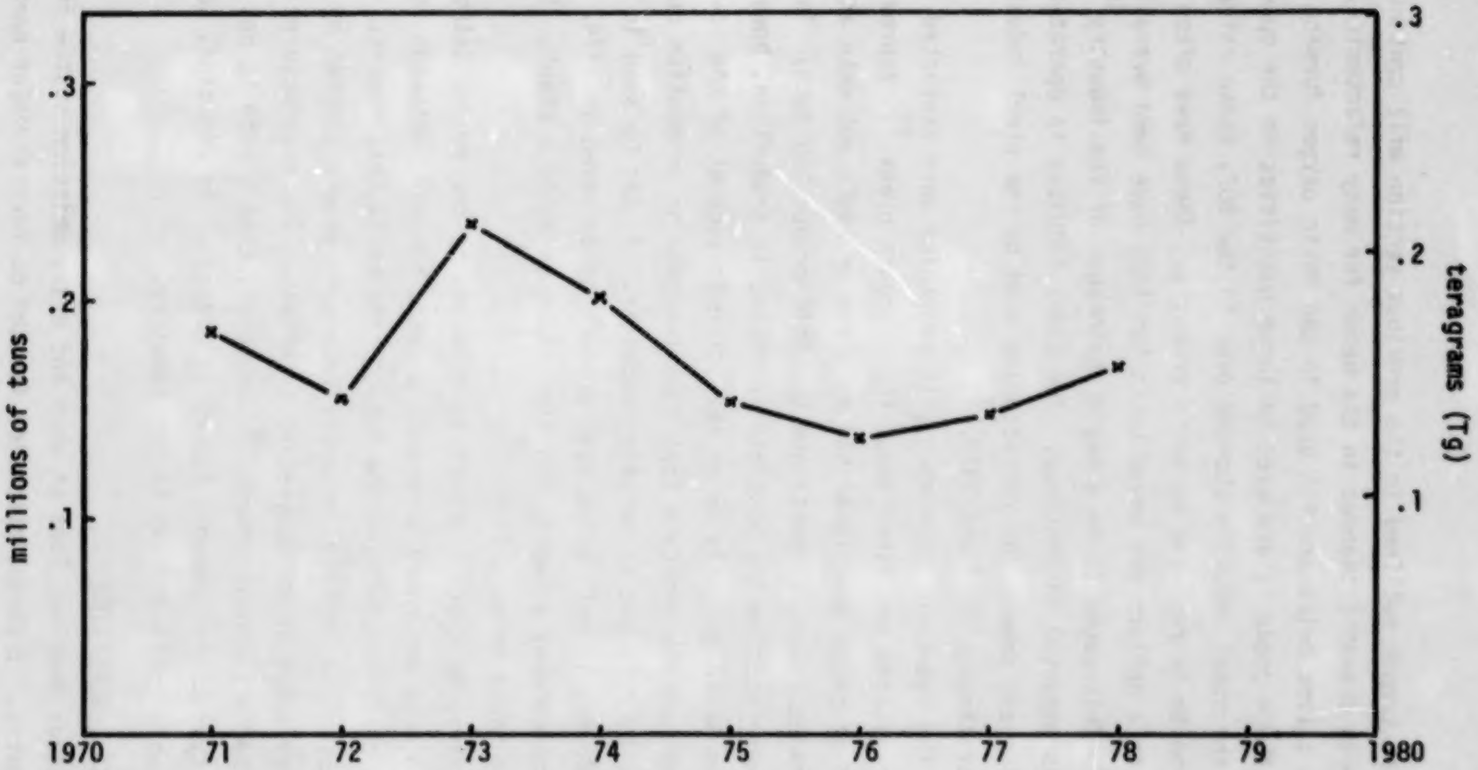


FIGURE 4-4 HISTORIC SHIPMENTS OF REFRACTORIES USING TAR & PITCH

Production data compiled using Department of Commerce data and average densities for each product line.[42]

the historical trends outlined in the previous section will continue. There have been dramatic changes in the needs for many refactories. Fireclay and silica brick are not used in the basic oxygen furnace (BOF). But these products are used in large quantities in the open hearth. As the steel industry changed over to the BOF, these refractories were abandoned to be replaced by basic products. These have often been more costly on a dollars per pound basis but they have been overall less expensive.[25] This seems to be a basic phenomenon of the industry[26] and this trend is expected to continue. The steel industry is operating below capacity and demand for refractories used by the steel industry has been flat through 1977 and 1978.[27]

During the course of this study, 15 companies were contacted by phone and/or visited and asked about their growth plans.[27] Approximately half of those questioned had no plans or would not make any specific comment. Several mentioned possible production cuts. The other half were considering possible increases in production, however, any increases would probably be in the unformed segment of the industry. Plant visits indicate that some increase in production could be accomplished by full use of existing capacity. As can be seen in Figure 4-3, the industry is well below peak production achieved in 1974.

Only one company actually had firm plans to build a plant. This plant will produce ceramic fiber.[28]

In summary, no overall growth is expected in the source category. Unformed products may experience some growth, however, emission sources involved in their manufacture are not considered in this report. Ceramic fiber production is expected to experience some growth spurred by the need for high temperature insulating materials. One manufacturer expects 15 percent annual growth.[29] However, this growth is not considered typical for ceramic fibers in general. In addition, ceramic fiber is a very small segment of the industry.

4.3 PROCESS DESCRIPTION

This study does not look at each and every emission source in the entire industry. Instead, attention focused on several major operations which are not covered under present and proposed NSPS studies. These operations are:

- Brick Firing in Kilns,
- Electric Arc Furnace Melting (fuse cast),
- Tar and Pitch Operations, and
- Ceramic Fiber Manufacture.

The rationale behind the selection of this set of operations is contained in Chapter 2.

This section outlines the total production processes that include the operations listed above. The objective is to allow the reader to place these processes into the total production perspective.

In each overall production process, up to four distinct phases may be present. These are:

- Raw Material Processing - the preparation of raw materials to be used in manufacture. This phase may include crushing, grinding, size classification, drying, and calcining. The terms dead-burning and sintering are frequently used in the industry. They refer to more intensive calcining. In this study the term calcining is taken to include these operations. Materials in this phase of production remain largely segregated.
- Forming - the mixing of raw materials under suitable conditions and subsequent forming into desired shapes. This step often occurs under wet or damp conditions which tend to reduce emissions.
- Firing - the heat process in which the refractory is brought up to high temperature to form the ceramic bond (vitrification) which gives the product its refractoriness. Additionally, melting of materials in arc furnaces is included in this phase.
- Final Processing - the final, post-firing steps in which the product may receive milling, grinding, sandblasting, tar impregnation and packaging.

Of course, some products skip some phases of the process altogether. An example is a tar bonded basic brick made from dolomite. Its principle advantage over other basic brick is the elimination of the costly firing step. Tar is used to hold the brick together until it is placed. Firing occurs in service when the furnace is first heated. In fuse cast production, the firing and forming steps are essentially reversed.

Figure 4-5 displays an overall process flowsheet for four major types of refractory products. The emission producing operations examined in this report are indicated by a bolder box.

4.3.1 Production of Fired Brick and Shapes

For the most part, fired brick is manufactured in a standardized manner. Product composition may range over all the compositions listed in Table 4-1, however, the bulk of products tend to be clay based firebrick and basic brick. Production is typically automated and high volume.

Figure 4-6 details the standard production process for most fired products. The production of unformed products is also shown, illustrating how this product bypasses the forming and firing steps.

Raw materials range from fireclays to refined alumina, magnesite, and zirconia. Calcining may occur before or after the crushing and grinding steps either at the refractory plant or the mine site. Clays, such as kaolin, in which high firing shrinkage is a problem, are frequently calcined. Occasionally, raw materials receive drying in rotary kilns to bring the moisture content down. These dryers typically operate on an intermittent basis depending on the rainfall the material has received in outside storage. Emissions from dryers are usually significant. However, these emissions are not considered in this study.

Most refractory magnesite is produced from sea water or salt brines. Magnesite used in basic refractories is usually heavily calcined and burned. If the product demands extreme refractoriness, magnesite may be first calcined at moderate temperatures of 1038 degrees C (1900 degrees F), then briquetted under high pressure. The briquettes are then refired at temperatures exceeding 1982 degrees C (3200 degrees F).[30] This product is commonly termed periclase. Calcining is usually

Figure 4-5 REFRACTORY MANUFACTURING FLOWCHART

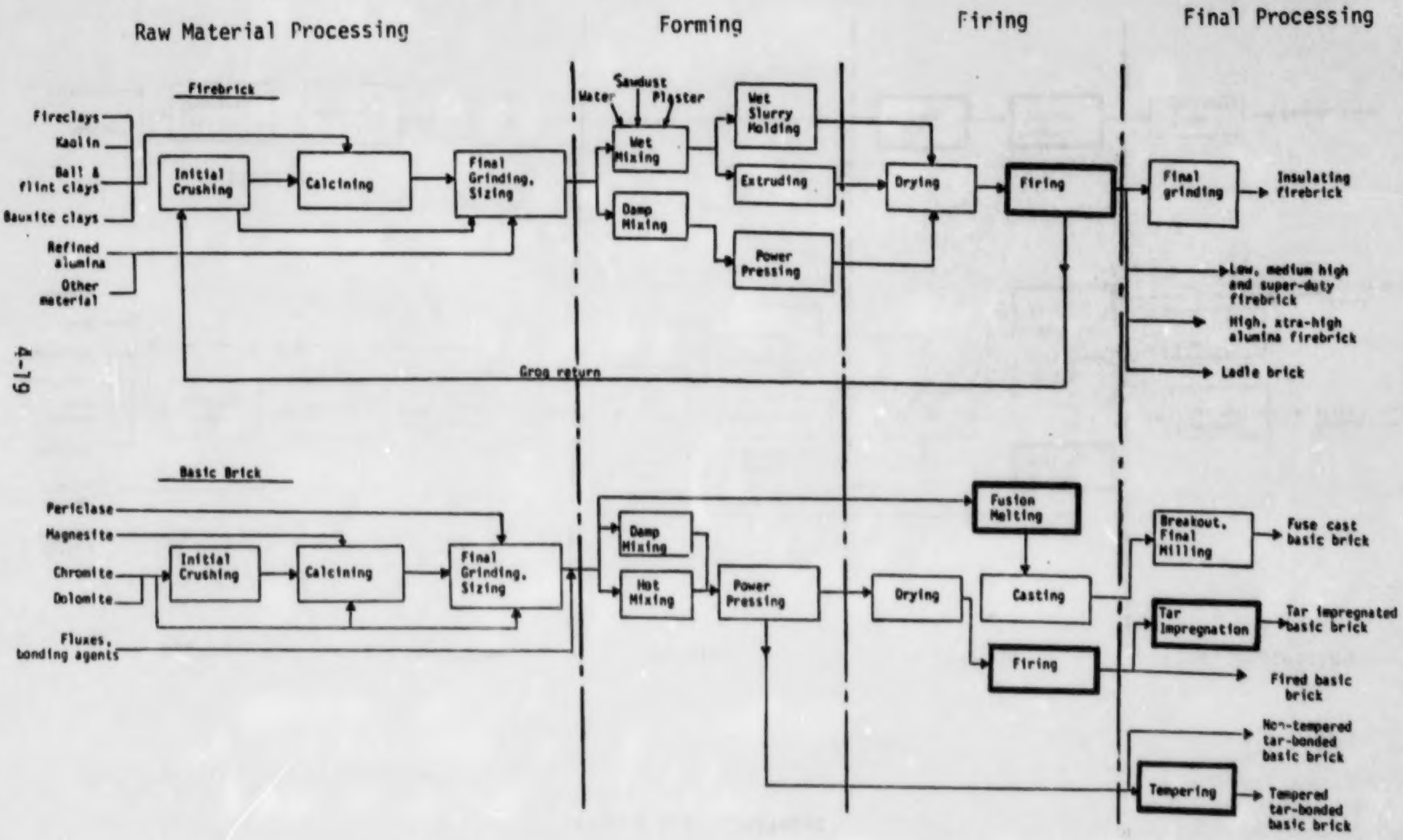
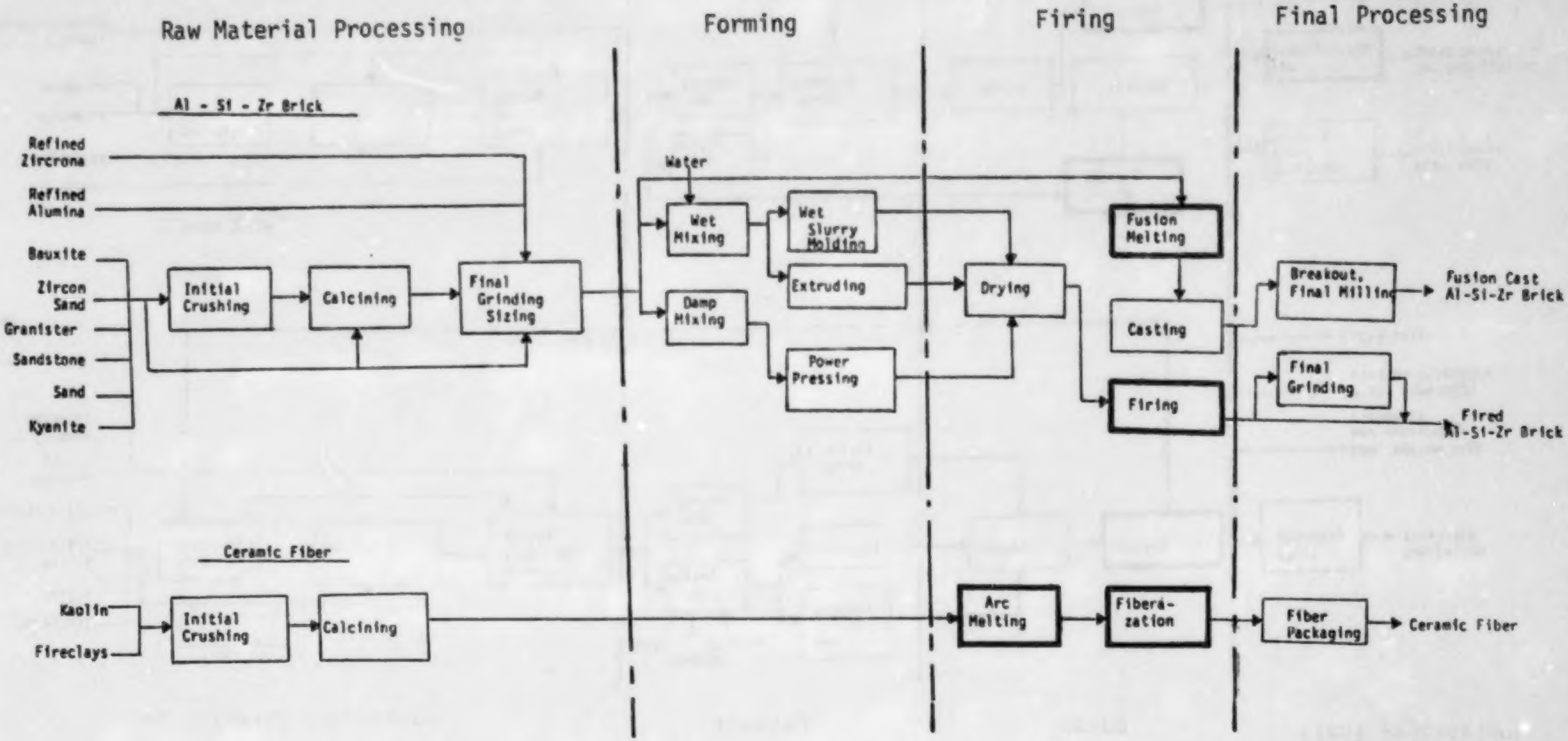

Raw Material Processing
Forming
Firing
Final Processing
Firebrick
Fireclays
Kaolin
Ball & flint clays
Bauxite clays
Refined alumina
Other material
Initial Crushing
Calcining
Final Grinding, Sizing
Water
Sawdust
Plaster
Wet Mixing
Damp Mixing
Wet Slurry Molding
Extruding
Power Pressing
Drying
Firing
Final grinding
Insulating firebrick
Low, medium high and super-duty firebrick
High, xtra-high alumina firebrick
Ladle brick
Grog return
Basic Brick
Periclase
Magnesite
Chromite
Dolomite
Fluxes, bonding agents
Initial Crushing
Calcining
Final Grinding, Sizing
Damp Mixing
Hot Mixing
Power Pressing
Drying
Fusion Melting
Casting
Firing
Breakout, Final Milling
Fuse cast basic brick
Tar Impregnation
Tar impregnated basic brick
Fired basic brick
Non-tempered tar-bonded basic brick
Tempering
Tempered tar-bonded basic brick

Figure 4-5 Continued


Raw Material Processing
Forming
Firing
Final Processing
Al - Si - Zr Brick
Refined Zircrona
Refined Alumina
Bauxite
Zircon Sand
Granister
Sandstone
Sand
Kyanite
Initial Crushing
Calcining
Final Grinding Sizing
Water
Wet Mixing
Damp Mixing
Wet Slurry Molding
Extruding
Power Pressing
Drying
Fusion Melting
Casting
Firing
Breakout, Final Milling
Final Grinding
Fusion Cast Al-Si-Zr Brick
Fired Al-Si-Zr Brick
Ceramic Fiber
Kaolin
Fireclays
Initial Crushing
Calcining
Arc Melting
Fibera-zation
Fiber Packaging
Ceramic Fiber

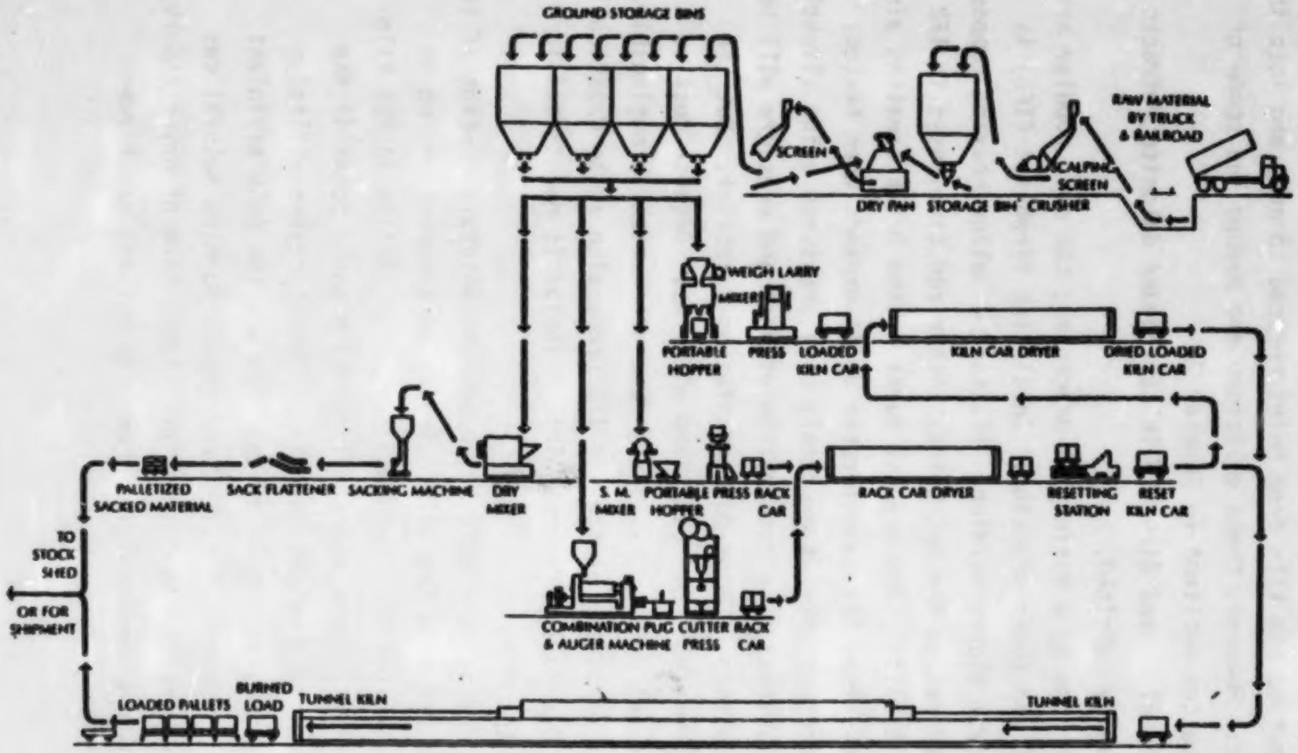

GROUND STORAGE BINS
RAW MATERIAL BY TRUCK & RAILROAD
SCALPING SCREEN
CRUSHER
STORAGE BIN
DRY PAN
SCREEN
WEIGH LARRY
MIXER
PORTABLE HOPPER
PRESS
LOADED KILN CAR
KILN CAR DRYER
DRIED LOADED KILN CAR
DRY MIXER
SACKING MACHINE
SACK FLATTENER
PALLETIZED SACKED MATERIAL
S. M. MIXER
PORTABLE HOPPER
PRESS
RACK CAR
RACK CAR DRYER
RESETTING STATION
RESET KILN CAR
COMBINATION PUG & AUGER MACHINE
CUTTER
PRESS
RACK CAR
TO STOCK SHED
OR FOR SHIPMENT
LOADED PALLETS
BURNED LOAD
TUNNEL KILN
TUNNEL KILN

FIGURE 4-6 FIRED PRODUCTS FLOWSHEET

Reference 43

done in large rotary kilns although vertical kilns and shaft furnaces are also used. Emissions from rotary kilns are the greatest. In fact, the briquetting step is introduced in high-fired products to prevent the entire magnesia input to the kiln from being reduced to dust and lost in the kiln gas stream. However, these emissions are beyond the scope of this project for reasons outlined in Chapter 2.

Dolomite may be also used directly in tar-bonded dolomite refractories. The dolomite is usually calcined.

Forming can be done by a variety of processes; the most popular are stiff mud extruding and power pressing. Insulating firebrick (IFB) is commonly molded by wet slurry molding. Plaster, a sulfur bearing compound, is sometimes used to set up the wet brick. Other additives used in IFB are sawdust and/or perlite. The sawdust burns in the brick creating air space while perlite serves the same purpose as it expands when heated. Power pressing is accomplished at extremely high pressures using slightly damp mixtures. Occasionally, a combination of heat and pressure will be used as in the production of high-duty insulating firebrick. But the majority of power pressing uses cool, damp mixtures. Because most of these processes use wet or damp mixtures, dust production is negligible. However, the effect of adding plaster in IFB production is to drastically increase SO_x emissions during firing. This emission is quantified in Chapter 5.

In most cases, it is desirable to reduce the moisture content of the formed brick before entering the kiln. Drying at temperatures up to 175 degrees C (350 Degrees F)[31] reduces energy consumption in the kiln and prevents excessive warping and spalling which would occur if the cool brick was immediately put in the kiln. Tunnel dryers utilizing waste heat from the cooling system of the kiln are the most efficient and popular dryers. However, direct-fired dryers burning natural gas are also used. The simplest (and least efficient) form of dryer observed during this study was a semi-enclosed room with natural gas burners scattered about.

Dryers are not believed to be significant emission sources except for emissions carried over from the kiln exhaust heat. Airflow in the dryer is low and dusting of the ware is unlikely. Combustion product emissions are small due to use of natural gas. Therefore, dryer emissions are not assessed as a separate emission source.

Firing may be accomplished in periodic kilns or continuous tunnel kilns. Tunnel kilns are by far the most popular and are shown on Figure 4-6.

Periodic kilns are usually round in shape giving rise to the popular terminology "beehive" kilns. Ware is stacked inside the kiln and the kiln opening is sealed with refractory brick. Firing is done through burner ports at a predetermined schedule to adhere to a temperature versus time firing relationship. Near the end of the cycle, the firing is terminated and the kiln is unloaded after cooling. Typical periodic kiln cycles might run around 8 to 25 days.

Tunnel kilns are fundamentally different in that the firing schedule is accomplished by movement of the brick through different zones of the kiln. The kiln itself never changes temperature. Brick is put on kiln cars which roll through the kiln on rails. Tunnel kilns are run continuously because temperature changes can damage the kiln. Shutdowns occur only for accidents (car wrecks) or major repairs. Residence time in the kiln might range from 8 hours to over 4 days.

Tunnel kilns enjoy several advantages over periodic kilns:

- Lower Energy Usage - Because the kiln itself is thermally static, losses involved in heating and cooling of the kiln are eliminated. Tunnel kilns make use of the waste heat generated in the cooling zones by recycling it to the preheat and firing zones or by channeling the heat to dryers. Also, circulation and heat distribution are decidedly better in tunnel kilns resulting in more even and efficient heat use.
- Easier Handling of Ware - Stacking the bricks on kiln cars lends itself to assembly line production methods. Handling labor is considerably reduced.

- Less Kiln Repair - The periodic heating and cooling of periodic kilns results in thermal shocks which cause cracking and spalling of the kiln structure and lining. Spot repairs are needed after every firing and regular rebuilding is required at much more frequent intervals than tunnel kilns.

The primary disadvantages of tunnel kilns are high capital cost, and inability to economically conform to changes in production type and volume. A special type of periodic kiln which mounts on hydraulic struts and is lowered over small kiln cars, called a car-bell kiln, is used for small specialized production. Shuttle kilns are another option for small batch production. These specialty kilns are mainly used in the manufacture of exotics and are not discussed further for the reasons outlined in Section 4.1.

Because of the advantages of tunnel kilns for most production, all new non-specialized brick firing kilns are expected to be of the tunnel kiln type.

Maximum firing temperatures in refractory tunnel kilns range from 1100 degrees C (2000 degrees F)[32] to 1870 degrees C (3400 degrees F).[33] Exhaust gas temperatures average approximately 300 degrees C (572 degrees F)[34] with flow rates around 700 m^3/min (24,720 cfm).[35] The longest kilns in the industry are over 190 meters (630 ft) in length.[36]

Emissions from kilns are generally low except for process fuel combustion products and kilns firing unusual ware. Kiln emissions are detailed in Chapter 5.

In some products, a final grinding and milling step is required due to warpage or shrinking of the brick. Additionally, some form of packaging usually occurs before the brick is shipped. Common shipping methods are pallets (often covered with heat shrink plastic), and cardboard cartons. Emissions from grinding and milling operations are generally captured and ducted to baghouses to prevent nuisance dust. These emissions were not examined due to reasons outlined in Chapter 2.

4.3.2 Production of Fused Products

Fuse or molten cast products generally use the same raw material preprocessing steps previously described. Raw materials are typically alumina, sand, zircon, and magnesia. Fuse cast production is generally lower volume and more specialized in nature than fired products. In contrast to the market for fired brick, the users of fuse cast refractories are less concentrated in the steel industry.

Electric arc furnaces are usually large steel pots lined with refractory material. Extending into the pot are three carbon electrodes which generate the arc. In one plant visited, charging was accomplished by hoisting small buckets to the lip of the furnace while pouring was accomplished by tipping the entire bucket.[37] Furnaces are usually operated batchwise 24 hours/day but are shut down for weekends. A typical charging/pouring cycle might last 2.5 hours. Temperatures approach 2500 degree C (4500 degree F)[38] for some types of fuse cast products.

Arc furnaces generate high amounts of particulate which boil off the molten pool. Control is accomplished by large, ducted airflow immediately above the furnace routed to baghouses. Capture efficiency may be considerably less than unity. No data is available to estimate capture efficiency.

Arc furnace emissions are considered in Chapter 5. Other emissions from fuse cast production, such as sandblasting of finished products, are not covered for reasons outlined in Chapter 2.

4.3.3 Tar and Pitch Operations

Basic brick is frequently manufactured or treated with tar and pitch derivatives for several reasons. Often the tar serves to add carbon to the brick which improves the refractoriness in basic environments. Also, the cohesiveness of the tar may be used to hold the brick together for handling and shipment, allowing the firing step to be bypassed at the refractory plant. Tar-bonded dolomite basic brick is an example of this type of product.

Two processes are potential sources of tar emissions. Impregnators take fired basic brick and impregnate the pore space in the brick using an autoclave process. This process involves placing the brick in a tank which is subsequently evacuated. Pressurized tar is then pumped in which fills the pore space in the brick.

The second process involves passing tar-bonded bricks through a tempering oven at temperatures of around 260 degrees C (500 degrees F). Calcined dolomite is usually mixed with hot tar and the resulting mixture is power pressed into bricks. Press fumes are considered negligible although no observation of this process could be made during this study. Some tar-bonded brick is shipped directly without tempering although it appears that the majority of production (85 percent) receives tempering.

Both impregnators and tempering ovens are significant sources of emissions. These emissions are quantified in Chapter 5.

4.3.4 Production of Ceramic Fiber

The recently developed ceramic fiber class of refractory products is dissimilar to all the products previously described. Production methods are similar to the mineral wool industry.

Calcined kaolin clay is the only raw material which was observed to be used for ceramic fiber, Electric arc melting of the clay is universally used. Two methods of forming the fibers are known. The first involves dropping the molten clay into an air jet where the clay is immediately blown into fine strands. This fiberization device is called a blowchamber. Another method involves mechanically forming the fibers in a centrifuge device which flings the molten mass from the center of a drum. After forming the fibers may be bagged for bulk use or formed into blankets, batts, boards or other forms. A light oil is usually used in the forming process and is burned off in small ovens.

Three processes in ceramic fiber are believed to be significant emission sources. These are the melting, fiberization, and the oven curing processes. The centrifuge forming does not appear to generate significant emissions; only blowchamber fiberization, melting, and oven curing emissions are covered in Chapter 5.

4.4 REFERENCES

1. The Refractories Institute. Product Directory of the Refractories Industry in the United States. Pittsburg, Pennsylvania, The Refractories Institute, 1978. 274 p.
2. Executive Office of the President, Office of Management and Budget, Statistical Policy Division. Standard Industrial Classification Manual. Washington, D.C., U.S. Government Printing Office, 1972. p. 139-142.
3. U.S. Dept. of Commerce, Bureau of the Census. 1977 Census of Manufactures, Industry Series, Nonclay Refractories. MC77-1-32E-6(P) Washington, D.C. June 1979.
4. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. 3rd. Edition. AP-42. Research Triangle Park N.C. August 1977. p. 8.5-1.
5. Argonne National Laboratory, Engineering and Environmental Systems Division. Engineering Note: Castable Refractory Plants, Argonne, Illinois. February 1978.
6. Reference 1
7. Arthur D. Little, Inc. Impact of an OSHA Regulation for Crystalline Silica upon Refractories Industry. Volume I, C-80884. Cambridge, Massachusetts. Prepared for The Refractories Institute, Pittsburgh, Pennsylvania. August 1978. p. II-1.
8. Reference 1
9. Reference 1
10. The Refractories Institute. Refractories. TRI Publication 7901. Pittsburgh, Pennsylvania. 1979. p.4.
11. Reference 1
12. Bozzelli, M. A Review of the U.S. Refractories Industry. General Services Administration, Federal Preparedness Agency. Washington, D.C. GSA/FPA TR-103. August 1976. p. 21.
13. Reference 10

14. Battelle Columbus Laboratories. Summary Report on a Study of the Refractories Industry -- Its Relationship to the U.S. Economy and Its Energy Needs. Columbus, Ohio. Prepared for The Refractories Institute. October 1973. p. i.

15. Storey, C. Energy and the Refractories Industry. Refractories Journal. 52: 26-28. November/December 1977.

16. Bird, R.E. Refractories in Transition. Reprint. Iron and Steel Engineer, 43: 1-8. October 1966.

17. U.S. Dept. of Commerce, Bureau of the Census. 1977 Census of Manufactures, Industry Series, Clay Refractories. MC77-1-32B-4(P). Washington, D.C. June 1979.

18. U.S. Dept. of Commerce, Bureau of the Census. 1977 Census of Manufactures, Industry Series, Nonclay Refractories. MC77-1-32E-6(P). Washington, D.C. June 1979.

19. Reference 17

20. Reference 18

21. North American Refractories Company. Sales Brochure. Cleveland, Ohio. 1979.

22. Jennings, M. S. Trip Report: C-E Refractories, St. Louis, Missouri. Radian Corp. Durham, N.C. December 11, 1979.

23. Jeffers, P. E. GREFCO Puts New Direct Bonded Brick Plant on Stream. Brick and Clay Record. 170: 16-19. May 1977.

24. Reference 2. p. 142.

25 Kusler, D. J. and R. G. Clarke. Impact of Changing Technology on Refractories Consumption. U.S. Dept. of the Interior, Bureau of Mines. Washington, D.C. Information Circular 8494. 1970. 68 p.

26. Reference 16

27. Telecon. Jennings, M. S., Radian Corporation with 15 refractory manufacturers. November, 1979.

28. Telecon. Jennings, M. S., Radian Corporation with Besalke, R. E., A. P. Green Company. November 19, 1979. Plans for production expansion.

29. Jennings, M. S. Trip Report: Babcock and Wilcox Company, Refractories Division, Augusta, Georgia. Radian Corp., Durham, N.C. December 3, 1979.

30. Havighorst, C. R. and S. L. Swift. Magnesia Extraction from Seawater. Chemical Engineering. 72: 84-86. August 1965.

31. Havighorst, C. R. and S. L. Swift. The Manufacture of Basic Refractories. Chemical Engineering. August 1965.

32. Jennings, M. S. Trip Report: Globe Refractories, Newell, West Virginia. Radian Corp. Durham, N.C. December 5, 1979.

33. Norton, F. H. Refractories. 4th ed. New York, McGraw-Hill, 1968. p. 165.

34. Moore, R. F. Dust and Pollution Control. Globe Refractories, Inc. Newell, W.V. (Presented at Technical Review and Performance Assessment of Globe Refractories, Inc. Air and Water Pollution Control Facilities. Chester, West Virginia. June 13, 1978.) p. 20.

35. Reference 34

36. Globe Refractories, Inc. Pouring Pit Refractories. Newell, West Virginia. December 1978.

37. Reference 22.

38. Reference 33. p. 189.

39. Reference 25. p. 6.

40. Reference 1.

41. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census. Current Industrial Reports, Refractories, Summaries for 1967 - 1978, Series MQ-32C. Washington, D.C. 1967 - 1978.

42. The Refractories Institute. Refractory Volume-to-Weight Conversion Factors. TRI News Bulletin, 4: 2. June 1968.

43. Reference 10. p. 11.

5. AIR EMISSIONS DEVELOPED IN THE SOURCE CATEGORY

This chapter identifies the emissions of concern in the source category and quantifies these emissions. The sources examined are not the only significant emission sources involved in refractory manufacture. The following sources are discussed:

- Brick Firing Kilns,
- Electric Arc Furnaces,
- Tar and Pitch Operations, and
- Ceramic Fiber Manufacture.

Other major sources are eliminated from this study for reasons discussed Chapter 2.

5.1 PLANT AND PROCESS EMISSIONS

This section is concerned with the development of emission factors for the sources identified above. The term emission factor, as used in this report, refers to a number which quantifies the emission per unit of product passing through a process. Both emission and process units are usually given in mass units. Thus, emission factor units typically take the form of kg/Mg (lb/ton).

Six emissions are considered potentially significant:

- Particulate - For the most part, particulate is the emission of primary concern in all refractory production processes,
- Sulfur Oxides - Sulfur oxide compounds are a major emission from the combustion of sulfur bearing fuel oil. The manufacture of two types of refractory brick also lead to significant sulfur oxide emissions. In one case, the sulfur is found in the raw clays used; in the other case, it is introduced to facilitate manufacture,
- Nitrous Oxides, Carbon Monoxide, Hydrocarbons - These gases are produced in the combustion of fossil fuels. Additionally, several types of refractories are manufactured using tars, pitchs, and oils resulting in hydrocarbon emissions, and

- Hydrogen Fluoride - The firing and fusing temperatures involved in refractory manufacture may cause significant evolution of fluoride gas if the raw materials contain fluoride compounds. This emission is briefly assessed.

A variety of data sources are used to quantify these emission species. EPA documents AP-40 and AP-42 were consulted for emission factors.[1,2] Only AP-42 factors are used directly. Other emission factors have been reported in previous studies and these are used where possible. The National Emission Data System (NEDS) reports emission rates and process rates in its listings; these rates may be used to estimate emission factors.[3] Finally, actual source test data was acquired during the course of this study from both government and industry sources. Unfortunately, its availability is limited and its accuracy is often questionable.

Table 5-1 presents the final emission factors derived in this study. In the following sections, the derivation of these factors is detailed.

5.1.1 Refractory Brick Kiln Emissions

As mentioned in Section 4, two types of firing kilns are presently in use in the industry; tunnel and periodic kilns. For purposes of this study, no distinction is made between the two methods of firing bricks and shapes. This decision is based on a variety of factors. First, the majority of products are currently fired in tunnel kilns. One study of brick kilns (including structural brick) showed over 75 percent of firing occurring in tunnel kilns.[4] Since this study was conducted, additional changeover to tunnel kilns is likely to have occurred. This study confirmed the preference toward tunnel kilns, especially in high volume production.

Second, emissions from tunnel kilns and periodic kilns firing the same ware are not thought to be significantly different. The two types of kilns subject the brick to essentially the same firing environment. Source test data tends to confirm this assumption.[5] AP-42 particulate emission factors for gas fired tunnel and periodic kilns firing brick products (including structural brick) are .02 kg/MG (.04 lb/ton) and

TABLE 5-1 UNCONTROLLED EMISSION FACTORS - kg/Mg (lbs/ton)

Process Source	Particulates	SO_x	CO	HC	NO_x	HF
Brick Firing Kilns						
Gas - IFB	.50 (1.0)	48 (96)	.02 (.04)	.01 (.02)	.075 (.15)	.5 (1.0)
Gas - Ladle	.50 (1.0)	1.5 (3.0)	.02 (.04)	.01 (.02)	.075 (.15)	.5 (1.0)
Gas - other	.50 (1.0)	--	.02 (.04)	.01 (.02)	.075 (.15)	.5 (1.0)
Oil - IFB	.78 (1.6)	49 (98)	--	.05 (.1)	.55 (1.1)	.5 (1.0)
Oil - Ladle	.78 (1.6)	2.9 (5.8)	--	.05 (.1)	.55 (1.1)	.5 (1.0)
Oil - other	.78 (1.6)	1.4 (2.8)	--	.05 (.1)	.55 (1.1)	.5 (1.0)
Arc Furnaces (non-fiber)	25 (50)	--	--	--	--	.65 (1.3)
Tar & Pitch Operations						
Impregnators	.92 (1.8)	--	--	--	--	--
Tempering Ovens	.23 (.45)	--	--	--	--	--
Ceramic Fiber						
Furnace Melting	5.2 (10)	--	--	--	--	--
Blowchamber	6.0 (12)	--	--	.45 (.90)	--	--
Curing Ovens	2.0 (4)	--	--	.50 (1.0)	--	--

.05 kg/MG (.11 lb/ton) respectively. This difference is negligible based on the final emission factors developed in this section. But, the emission rate in periodic kilns is likely to be highly dynamic due to the cyclic nature of the firing schedule. Thus, periodic kilns with similar long term emission volumes may have short term emission rates many times that of tunnel kilns. These rates may lead to high opacity emissions for short periods. However, since this report is primarily concerned with the estimation of overall annual emissions, this factor is not considered.

For these reasons, kiln emission factors are developed using tunnel kiln data. The use of these factors to approximate present periodic kiln emissions is not likely to introduce serious error. And it is likely the emission factors so developed will more closely estimate the emissions generated from new sources since major new kilns will likely be of the tunnel kiln type.

No simplifying assumption can be made concerning firing fuels. Gas and oil fired kilns have decidedly different products of combustion. Separate emission factors are developed for each.

The use of coal for refractory brick firing was investigated. No use of coal in refractory firing nor any plants to use were discovered during this study. The Refractory Institute has consistently maintained that the use of coal in tunnel kilns requires the solution of numerous technical problems the most severe being product contamination by fly ash.[6] One manufacturer has conducted a pilot plant operation producing ladle brick in a coal fired kiln. The operation was shelved due to various problems, the most severe being fly ash buildup in the kiln.[7] Another deterrent to coal use is the limited firing temperatures that can be attained. It is estimated that only 35 percent of clay refractory production and virtually none of non-clay production could be converted.[8] Barring unforseen technological breakthroughs or astronomical gas prices, it is unlikely that coal firing will be used for tunnel kilns in the next five years.

5.1.1.1 Particulate Emissions. At the onset of this project, it was generally assumed that refractory kilns would show lower particulate emission factors than kilns firing other types of brick (primarily structural brick) using the same firing fuels. This assumption was based on the argument that refractory kilns fire materials of higher purity and quality. The data collected during this study did not demonstrate any discernible difference between particulate emission factors and brick types. However, it should be emphasized that a kiln firing structural brick generally fires a much greater amount of brick for a given stack gas flowrate. Refractory kilns use more air due to the higher firing temperatures which require more fuel use (and thus combustion air), and much longer residence time in the kiln. The end result of this difference in gas flowrate per brick is a much higher grain loading for stack gases in structural brick kilns than is the case for refractory brick kilns even though emission factors may be similar. These loadings may lead to very high opacity readings due to extremely fine, highly reflective particles. Because data on refractory kilns was lacking and no correlation between particulate emissions and brick type could be established, particulate emission factors for firing kilns were developed, in part, using non-refractory brick kiln data.

Table 5-2 represents the particulate source tests and other data collected for uncontrolled gas fired tunnel kilns. As can be seen, the scatter in data is considerable ranging from a low of .02 kg/mg (.04 lb/ton reported in AP-42 to a high of 1.19 kg/Mg (2.38 lb/ton). Initially an attempt was made to correlate the results to the type of brick fired or pecularities of a given kiln. Unfortunately, no clear trend presented itself. The scatter apparently results from two factors. First, kilns fire a tremendous range of products from extremely dirty clays containing high percentages of organic matter to highly processed mixtures of aluminas and magnesites. The data sample is insufficient to establish the complex relationships. Second, evidence exists to suggest that considerable organic matter may be existing as organic vapors under stack conditions.[9] Whether this material shows up in a given particulate test is questionable. The variability in testing method and skill introduces considerable inaccuracy in the results.

TABLE 5-2 UNCONTROLLED GAS-FIRED TUNNEL KILN PARTICULATE EMISSION FACTOR DATA - kg/Mg (lb/ton)

No. of Point Sources Tested	Emission Factor Range	Average Emission Factor	Reference	Notes
4	.021 - 1.19 (.042 - 2.38)	.360 (.719)	27	a
1	.59 (1.17)	.59 (1.17)	28	b
3	.08 - .5 (.16 - 1.07)	.24 (.48)	29	c
1	1.13 (2.25)	1.13 (2.25)	30	d
1	.57 (1.14)	.57 (1.14)	31	e
7	.10 - 1.03 (.207 - 2.05)	.56 (1.13)	32	f
1	.89 (1.78)	.89 (1.78)	33	g
Unknown	.02 (.04)	.02 (.04)	34	h

Notes:

a - Raw particulate emission factors as reported in Appendix A, Monsanto Source Assessment document 12 - Brick Kilns
b - Source Category Survey Report, Clay and Brick Manufacturing Industry
c - Journal article on brick kiln emissions
d - Confidential data for basic brick kiln
e - Stack test data for Globe Refractories firing ladle brick, 1977
f - Extracted from NEDS data base
g - Stack test data for Globe Refractories firing ladle brick, 1978
h - AP-42

In deriving an average emission factor, a variety of weighting schemes were used in order to express the confidence displayed in any one data piece. No coherent weighting scheme produced significantly different results from a simple arithmetic average of the numbers in Table 5-2. Thus, an approximate value of .50 kg/Mg (1.0 lb/ton) is used as an uncontrolled particulate emission factor for firing kilns.

Data on oil-fired kilns is insufficient to arrive at a particulate emission factor. Using the AP-42 factor for oil fired kilns would be inconsistent with the previously derived factor as the AP-42 value is lower. The difference between the gas and oil factors can be expected to quantify the addition of particulate combustion products from the oil. Therefore, the difference between the two factors quantifies the additional particulate generated by burning oil rather than gas. Using this logic, the particulate emission attributable to the oil can be calculated:

AP-42	oil fired factor	.3 kg/Mg (.6 lb/ton)
AP-42	gas fired factor	.02 kg/Mg (.04 lb/ton)
Difference attributable to oil particulate.		.28 kg/mg (.56 lb/ton)

Adding this number to the emission factor for gas fired kilns give a result of .78 kg/Mg (1.56 lb/ton) for an oil fired kiln particulate factor.

Visible emissions from uncontrolled refractory brick kilns observed during this study were generally very light. In most cases no visible emissions were noted.

5.1.1.2 Sulfur Compound Emissions. Three major sources of sulfur emissions in tunnel kiln firing are identified:

- Fuel Oil Combustion - Refractory kilns are fired by virtually all types of residual and distillate oil. Sulfur contents of these fuels typical range from .3 to 2 percent by weight,[10]
- Sulfur Bearing Clays - Many types of clay contain considerable amounts of sulfur. But most refractory clays

are calcined prior to use which oxidizes the sulfur. One major type of refractory, ladle brick, uses a raw clay which usually is high in sulfur. Sulfur oxide emissions from this product are considered separately, and

- Plaster Addition - Low and medium temperature insulating firebrick (IFB) is commonly made by wet slurry molding. Plaster is added to the slurry to allow the green brick to be handled prior to firing. The plaster oxidizes in the kiln resulting in high sulfur emissions.

Since the majority of source tests on tunnel kilns have been conducted on gas fired kilns, no test data is available to estimate sulfur compound emissions due to oil combustion products. AP-42 lists an emission factor based on the percent sulfur in the fuel derived from extensive fuel oil combustion testing. Since data is available concerning the distribution of oil use by type in the industry, a sulfur oxide emission factor for oil combustion is determined using the factor in AP-42.

The Refractory Institute submitted information to the U.S. Department of Commerce which indicated that 68.8 percent of fuel oil use in the industry was distillate types #1 and #2 with the remainder residual types #3 thru #6.[11] Exxon Corporation provided a leading refractory manufacturer the following breakdown of sulfur content in oils.[12]

#2 fuel oil - .3 percent by weight
#4 fuel oil - 1.4 percent by weight
#5 fuel oil - 1.6 percent by weight
#6 fuel oil - 1.5 - 2.0 percent by weight

A telephone survey of the industry revealed no use of #1 oil.[13] Furthermore, .3 percent sulfur content is often required by state regulations for sulfur emission control. Therefore, .3 percent sulfur content is judged to be representative of 68.8 percent of industry oil use. An average of the remaining residual percentages results in a sulfur content of 1.58 percent for the remaining 31.2 percent of oil use. Combining the two sulfur contents by their weighted use results in an average sulfur content in refractory kiln oils of .7 percent. Using this percentage in the formula in AP-42 results in a final fuel oil combustion product emission of 1.4 kg/Mg (2.8 lb/ton).

Gas fired sulfur combustion emissions are assumed negligible in AP-42 and this study.

The type of clay used to manufacture ladle brick is typically high in sulfur. The contribution of ladle brick to sulfur emissions is estimated using stack tests from the largest ladle brick manufacturer in the U.S. and emission factors reported in a journal article. Both kilns are gas fired. Table 5-3 shows this data. These two factors are averaged to arrive at an SO_x emission factor for gas fired ladle brick of 1.5 kg/Mg (3.0 lb/ton). For oil fired ladle brick, the fuel oil combustion sulfur emission is added to this number to yield 2.9 kg/Mg (5.8 lb/ton).

The plaster used in IFB production is burned at tunnel kiln temperatures. Data submitted to a state agency, believed to use a mass balance analysis (assuming total volatilization of the sulfur in the plaster), indicated emission factors of 52.8 kg/Mg (105.6 lbs/ton) and 42.8 kg/Mg (85.6 lbs/ton).[14] Given temperatures in the kiln of greater than 1427 degrees C (2600 degrees F) and retention times on the order of eight hours,[15] this approach is judged to be sound. Therefore, these two values are averaged to arrive at a gas fired IFB emission factor of 47.8 kg/mg (95.6 lbs/ton). For oil fired IFB, the fuel oil combustion product emission is added to this number to yield 49.2 kg/Mg (98.4 lbs/ton).

5.1.1.3 $\underline{NO_x, \text{HC, CO Emissions}}$. No source date is available to quantify these emissions. The production of these gases results almost entirely from fuel combustion products. AP-42 lists emission factors for these gases and they are used in this study. However, it should be noted that variation in air-fuel ratio and burner system design could alter these rates considerably. All modern tunnel kilns observed in this study are equipped for complete control of the ratio in various firing zones of the kiln.[16] Therefore, it is believed that the emission factors in AP-42 are reasonably close to the actual emission factors.

TABLE 5-3 UNCONTROLLED GAS-FIRED TUNNEL KILN SO_x EMISSION FACTOR DATA - kg/Mg (lb/ton)

No. of Point Sources Tested	Emission Factor	Reference	Notes
1	1.39 (2.77)	35	a
1	1.66 (3.31)	36	b

Notes:

a - Stack test for SO_2 at Globe Refractories, 1977 (SO_3 assumed negligible).

b - Journal article on brick kiln emissions, Plant D data.

5.1.1.4 Fluoride Emissions. Because of harmful effects on animals and vegetation, fluoride emissions are briefly assessed. Judging from the literature,[17, 18, 19] it would appear that fluoride emissions are influenced by a complex set of factors including clay fluoride content, sulfur content, lime content, fuel type used, firing temperature, and other factors. The assessment of this interaction is beyond the scope of this study.

The average of four emission factors presented in one source indicated a factor of .24 kg/Mg (.47 lb/ton).[20] AP-42 gives a value of .50 kg/Mg (1.00 lb/ton). Because no conclusive data could be found to refute the AP-42 value, it is used.

5.1.2 Arc Furnace Emissions

Electric arc furnaces are used to melt (fuse) refractory materials for subsequent pouring into sand molds. The arc generated in the furnace vessel creates a turbulent fluxing action which entrains considerable particulate. This particulate escapes the arc furnace vessel as a fugitive and is usually drafted away with large volumes of air to a control device. The extremely high temperatures (up to 2482 degrees C (4500 degrees F))[21] also result in fluoride emissions. Other gaseous emissions are possible, however, data was insufficient to estimate their extent and magnitude. Since most materials used in fuse cast refractories are non-clay and of high purity, these emissions are believed to be small.

5.1.2.1 Particulate Emissions. Table 5-4 displays the available data concerning particulate emissions. The average of the data was very close to the AP-42 value. Therefore, the AP-42 factor of 25 kg/Mg (50 lb/ton) was used.

5.1.2.2 Fluoride Emissions. The only source reporting actual test data is a fuse cast refractories screening study.[22] Conducted in 1972, it reported a test in which the fluoride emission factor varied between .35 kg/mg (.7 lb/ton) and .95 kg/Mg (1.9 lb/ton) expressed as HF. The average of these two values is the number found in AP-42. This factor of .65 kg/Mg (1.3 lb/ton) is slightly higher than the kiln fluoride

TABLE 5-4 UNCONTROLLED ELECTRIC ARC FURNACE PARTICULATE EMISSION FACTOR DATA - kg/Mg (lb/ton)

No. of Sources Tested	Emission Factor	Reference	Notes
1	4.64 (9.27)	37	a
2	24.9 (49.8)	38	b
Unknown	42.5 (85)	39	c
3	25 (50)	40	d

Notes:

a - Stack test data from C-E Refractories, St. Louis.

b - NEDS data base .

c - RTI Screening Study of Castable Refractories, 1972.

d - AP-42

emission factor reported earlier. This is logical due to the higher melt temperatures leading to complete evolution of fluoride as HF as opposed to the near complete evolution at brick firing temperatures. This value is used in this study. However, it should be emphasized that the production of fluoride emissions is highly complex and varies considerably.

5.1.3 Tar and Pitch Operations

Several varieties of basic brick (used in applications with high pH environments) use tar and pitch as an additive to the brick. This addition may serve two purposes. First, it gives the brick coking characteristics necessary for some applications. The tar serves to add carbon to the brick increasing its refractoriness. Second, it may serve as a cohesive agent to hold the brick together during transportation and handling. This allows the brick to be shipped unfired to be fired on site in its intended application. Energy savings are considerable. Tar bonded dolomite bricks are very popular in basic steel making operations.

The classification of emissions from these operations as particulate or hydrocarbons is difficult to determine. The NEDS data used to estimate emissions simply lists emissions as particulates. In reality, emissions from these sources can be expected to be high molecular weight organic compounds existing in aerosol, and gaseous forms. However, these emissions are classified as particulates because of the manner in which the emissions are listed in the NEDS data used.

Two sources are identified as potentially significant emission sources: tar impregnators and tempering ovens. The only data source which lists emission rates is the NEDS data base. This data is shown in Table 5-5. Fortunately, most of the entries list "Source Test" as the emission estimation method and the factors are in rough agreement. Averages of the values are used. For impregnators an emission factor of .92 kg/Mg (1.84 lb/ton) is used. For tempering ovens a factor of .23 kg/Mg (.45 lb/ton) is used.

Tar emissions are also possible from melt tanks used to prepare tar for use. No data is available to assess this emission.

TABLE 5-5 UNCONTROLLED TAR & PITCH OPERATIONS PARTICULATE EMISSION FACTOR DATA - kg/Mg (lbs/ton)

No. of Sources	Emission Factor	Device
1	1.49 (2.97)	Impregnator
1	.354 (.708)	Impregnator
1	.133 (.265)	Tempering Oven
1	.233 (.465)	Tempering Oven
1	.303 (.606)	Tempering Oven

Note:

All data extracted from NEDS data base.

5.1.4 Ceramic Fiber Emissions

An effort was made to acquire source test data for the rapidly growing ceramic fiber industry. None was found during the course of this study. However, it is noted that the production of ceramic fiber is essentially similar to the production of mineral wool. A source category survey was recently completed for this industry.[23] Two major differences are noted between the two industries:

- The mineral wool industry uses rock and slag for raw materials; ceramic fiber uses clays, and
- The method of melting raw material in mineral wool manufacture is cupolas. Ceramic fiber production uses electric arc furnaces.

One piece of NEDS data is available. A recently completed plant lists furnace melting emissions and process rates resulting in a particulate emission factor of 2.35 kg/Mg (4.70 lb/ton).

Furthermore, the mineral wool report mentions the possible use of arc furnaces to replace cupolas and potential emission reductions through this conversion. The particulate emission factor for cupolas is given as 8 kg/MG (16 lb/ton). As a rough estimate of arc furnace emissions, the two values are averaged to yield an estimate for particulate emissions of 5.2 kg/MG (10.4 lb/ton).

No data is available to estimate blowchamber and curing oven emissions. However, the process description in the mineral wool study is virtually identical to the process observed at a ceramic fiber plant visited during this study.[24] Therefore, the mineral wool factors for these two processed are used to estimate particulate and hydrocarbon emissions from ceramic fiber manufacture. The particulate factors adopted are 6.0 kg/Mg (12 lb/ton) and 2.0 kg/Mg (4 lb/ton) for blowchambers and curing ovens respectively. Use of oils to lubricate the fibers and the machinery used to handle and form the fibers results in hydrocarbon emissions also. The mineral wool factors adopted are .45 kg/Mg (.90 lb/ton) and .50 kg/Mg (1.0 lb/ton) for the two processes.

5.2 UNCONTROLLED EMISSIONS FROM TYPICAL PLANTS

Annual production data for typical plants is estimated by taking a fraction of the total national production volumes. These fractions were based on the number of plants with the emission sources examined. The total national production estimate uses the data for 1977 provided by the Department of Commerce.[25] This was the last year that summary statistics are available. This data is provided in terms of standard nine inch bricks, which are then converted to tons using average densities for various products provided by The Refractory Institute.[26] The production data is summarized in Table 5-6.

Using this data and the uncontrolled emission factors presented earlier, emissions can be estimated for typical uncontrolled plants. This data is presented in Table 5-7. Readers should note that the emissions are not totaled over all the processes. Refractory plants are usually highly specialized. Each plant's product line is such that only one of the four major processes is conducted on site. Therefore, the emissions are subtotaled for each process class but are not totaled overall. The subtotals can be considered representative of a moderate to large plant specializing in a particular type of product.

5.3 EMISSIONS FROM A PLANT CONTROLLED TO MEET A TYPICAL STATE IMPLEMENTATION PLAN

With few exceptions, the only state regulations pertaining to the operations under consideration are process weight regulations for particulates and visible emission standards. In some cases, visible emission standards have been the constraining factor on plant emissions. In fact, the only operating control device on tunnel kilns was installed to meet an opacity standard. Kiln particulate emissions tend to be submicronic in size with high reflectivity.

Many states use a process weight regulation of the form $E = 4.10P^{67}$ where E is the allowable emission rate in lb/hr and P is the process rate in tons/hr. Ohio uses this formula and has 18 percent of the plants in the country. This regulation is considered to be typical.

Process rates in tons/hr are obtained by dividing the annual production volumes by the number of hours the process operates in a year.

TABLE 5-6 PRODUCTION LEVELS - Mg/yr (ton/yr)

Process	National		Typical Plants	
Brick Firing Kilns				
Gas - IFB	9450	(10400)	189	(208)
Gas - Ladle	248000	(272800)	4960	(5456)
Gas - Other	1392800	(1532100)	27860	(30640)
Oil - IFB	2360	(2600)	47	(52)
Oil - Ladle	62000	(68200)	1240	(1364)
Oil - Other	348000	(383000)	6964	(7660)
Arc Furnaces (non-fiber)	108000	(118800)	10800	(11880)
Tar & Pitch Operations				
Impregnators	88500	(97300)	8850	(9730)
Tempering Ovens	30200	(33200)	3020	(3320)
Ceramic Fiber				
Furnace Melting	13600	(15000)	3490	(3750)
Blowchamber	13600	(15000)	3490	(3750)
Curing Ovens	13600	(15000)	3490	(3750)

Notes:

1. Production levels based on 1977 data furnished by U.S. Dept. of Commerce and average densities furnished by The Refractory Institute.
2. Typical plant levels based on following plant fractions
   Brick - 2% of industry
   Arc Furnaces - 10% of industry
   Tar & Pitch - 10% of industry
   Ceramic Fiber - 25% of industry

TABLE 5-7 UNCONTROLLED EMISSIONS FROM TYPICAL PLANTS Mg/yr (tons/yr)

Process Source	Particulates	---	SO_x		CO		HC		NO_x		HF	
Brick Kilns												
Gas - IFB	.095	(.105)	9.08	(10.0)	.0004	(.004)	.002	(.002)	.014	(.015)	.095	(.105)
Gas - Ladle	2.48	(2.73)	7.44	(8.18)	.099	(.109)	.050	(.050)	.372	(.409)	2.48	(2.73)
Gas - Other	13.9	(15.3)	--		.577	(.613)	.278	(.306)	2.09	(2.30)	13.9	(15.3)
Oil - IFB	.037	(.041)	2.30	(2.53)	--		.002	(.003)	.026	(.028)	.024	(.026)
Oil - Ladle	.967	(1.07)	3.60	(3.96)	--		.062	(.068)	.682	(.750)	.620	(.682)
Oil - Other	5.43	(5.97)	9.75	(10.7)	--		.348	(.383)	3.83	(4.21)	3.48	(3.83)
TOTAL	22.9	(25.2)	32.2	(35.4)	.68	(.75)	.74	(.82)	7.0	(7.7)	20.6	(22.7)
Arc Furnaces	270	(297)	--		--		--		--		7.02	(7.72)
Tar & Pitch Operation												
Impregnators	8.14	(8.96)	--		--		--		--		--	
Tempering Ovens	.69	(.76)	--		--		--		--		--	
TOTAL	8.83	(9.71)	--		--		--		--		--	
Ceramic Fiber												
Furnace Melting	17.7	(19.5)	--		--		--		--		--	
Blowchamber	20.5	(22.6)	--		--		1.53	(1.69)	--		--	
Curing Ovens	6.82	(7.50)	--		--		1.70	(1.87)	--		--	
TOTAL	45.0	(49.5)	--		--		3.2	(3.6)	--		--	

Tunnel kilns usually operate continuously 365 days/year and 24 hrs/day. The other processes operate continuously except for weekends. For these, 260 days/year and 24 hrs/day are used. The various types of kiln production are summed for this determination. This gives a process rate typical for one large tunnel kiln. Using these rates, the allowable emissions are calculated using the typical regulation. Table 5-8 shows the maximum emissions from plants controlled to a typical state regulation. In general, state regulations apply to particulate emissions. Of these emissions, only arc furnaces and ceramic fiber manufacturing operations require any control.

5.4 TOTAL NATIONWIDE EMISSIONS

Table 5-9 presents the total uncontrolled nationwide emissions from the source category. This data was compiled by multiplying the emission factors in Table 5-1 by the national production volumes in Table 5-6.

To estimate the actual nationwide emissions an attempt was made to assess the present degree of control. Kilns are almost totally uncontrolled. Arc furnaces typically use baghouses which can be expected to give excellent particulate removal efficiencies. However, observation of a working arc furnace during a plant visit indicated capture efficiencies significantly less than unity. No data is available to estimate an average capture efficiency for the process. As well, very little data is available for tar and pitch and ceramic fiber processes.

In the absence of good information to base an assessment of the current degree of control, the typical state regulation is used to quantify actual nationwide emissions. The results are shown in Table 5-10.

TABLE 5-8 EMISSIONS FROM PLANTS CONTROLLED TO TYPICAL STATE REGULATION

Process Source	Process Rate		Particulates	SO_x	CO	HC	NO_x	HF
	Mg/hr	(ton/hr)	Mg/yr (ton/yr)					
Brick Firing Kilns	4.71	(5.18)	22.9 (25.2)	32.2 (35.4)	.68 (.75)	.74 (.82)	7.0 (7.7)	20.6 (22.7)
Arc Furnaces	1.72	(1.90)	17.8 (19.7)	--	--	--	--	7.02 (7.72)
Tar & Pitch Operations								
Impregnators	1.42	(1.56)	8.14 (8.96)	--	--	--	--	--
Tempering Ovens	.484	(.532)	.69 (.76)	--	--	--	--	--
Total			8.83 (9.71)					
Ceramic Fiber								
Furnace Melting	.545	(.600)	11.6 (12.8)	--	--	--	--	--
Blowchamber	.545	(.600)	11.6 (12.8)	--	--	1.53 (1.69)	--	--
Curing Ovens	.545	(.600)	6.8 (7.5)	--	--	1.70 (1.87)	--	--
Total			30.0 (33.1)	--	--	3.23 (3.56)	--	--

TABLE 5-9 TOTAL UNCONTROLLED NATIONWIDE EMISSIONS Mg/yr (tons/yr)

Process Source	Particulates	SO_x	CO	HC	NO_x	HF
Brick Kilns						
Gas - IFB	4.75 (5.23)	454 (499)	.20 (.22)	.10 (.11)	.70 (.77)	4.8 (5.2)
Gas - Ladle	124 (136)	372 (409)	4.9 (5.4)	2.5 (7.8)	18.6 (20.5)	124 (136)
Gas - Other	695 (764)	--	28.9 (31.7)	13.9 (15.3)	104 (115)	695 (765)
Oil - IFB	1.85 (2.04)	115 (127)	--	.10 (.11)	1.3 (1.4)	1.2 (1.3)
Oil - Ladle	48.4 (53.2)	180 (198)	--	3.1 (3.4)	34.1 (37.5)	31.0 (34.1)
Oil - Other	272 (299)	488 (536)	--	17.4 (19.1)	192 (211)	174 (191)
Subtotal	1145 (1260)	1610 (1771)	34.0 (37.4)	37.0 (40.7)	350 (385)	1030 (1133)
Arc Furnaces	2700 (2970)	--	--	--	--	70.2 (77.2)
Tar & Pitch Oper.						
Impregnators	81.4 (89.5)	--	--	--	--	--
Tempering Ovens	6.9 (7.59)	--	--	--	--	--
Subtotal	88.3 (97.1)	--	--	--	--	--
Ceramic Fiber						
Furnace Melting	70.8 (77.9)	--	--	--	--	--
Blowchamber	82.0 (90.2)	--	--	6.1 (6.7)	--	--
Curing Ovens	27.2 (29.9)	--	--	6.8 (7.5)	--	--
Subtotal	180 (198)	--	--	13.0 (14.3)	--	--
OVERALL TOTAL	4114 (4526)	1609 (1771)	34.0 (37.4)	50.0 (55.0)	350 (385)	1100 (1210)

TABLE 5-10 NATIONWIDE EMISSIONS ASSUMING SIP CONTROL
Mg/yr (ton/yr)

Process Source	Particulate	SO_x	CO	HC	NO_x	HF
Brick Firing Kilns	1145 (1260)	1610 (1771)	34.0 (37.4)	37.0 (40.7)	350 (385)	1030 (1133)
Arc Furnaces	178 (197)	--	--	--	--	70.2 (77.2)
Tar & Pitch Operations						
Impregnators	81.4 (89.6)	--	--	--	--	--
Tempering Ovens	6.9 (7.6)	--	--	--	--	--
Ceramic Fiber						
Furnace Melting	46.4 (51.0)	--	--	--	--	--
Blowchamber	46.4 (51.0)	--	--	6.1 (6.7)	--	--
Curing Oven	27.2 (29.9)	--	--	6.8 (7.5)	--	--
TOTAL	1531 (1685)	1609 (1771)	34 (37)	50 (55)	350 (385)	1100 (1210)

5.5 REFERENCES

1. Danielson, J. A., (ed). Air Pollution Engineering Manual. 2nd ed. U.S. Environmental Protection Agency. Research Triangle Park, N.C. AP-40. May 1973
2. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. 3rd Edition. AP-42. Research Triangle Park, N.C. August 1977.
3. U.S. Environmental Protection Agency. National Emission Data System. Computer printouts for SIC 3255 and SIC 3297. October, 1979. 1187 p.
4. Boyle, T. F. and Reznik, R. B. Brick Kilns (Draft). Monsanto Research Corporation. Dayton, Ohio. Source Assessment Document No. 12. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, N.C. August 1975.
5. Environmental Testing, Inc. Source Sampling Report for North State Pyrophyllite Co., Inc. Charlotte, N.C. August 1978.
6. Letter and attachments from Widing, J. W., Jr., The Refractories Institute, to Schechter, S., Energy and Environmental Analysis. June 27, 1977. p. 2. Preferred fuels for manufacturing refractories.
7. Globe Refractories, Inc. Globe Refractories Experiences in Tunnel Kiln Coal Firing and Related Pollution Control. Newell, West Virginia. No date.
8. Letter and attachments from Porter, S.C., Globe Refractories, to Schechter, S., Energy and Environmental Analysis. July 16, 1977. Attachment, p. 3. Potential for coal firing of refractories.
9. Reference 4. p. 471.
10. Exxon Company, Southeastern Region. Flashnote! Distillate and Residual Fuels Typical Inspections. Atlanta, Georgia. September 16, 1974.

11. Letter and attachments from Tucker, Bradford S., The Refractories Institute to Federal Energy Administration, Voluntary Energy Reporting Program. April 29, 1977. Tables 1-4. Voluntary Industrial Energy Conservation Progress Report.

12. Reference 11

13. Telecon. Jennings, M. S., Radian Corporation with refractory manufacturers. November, 1979.

14. Babcock & Wilcox Co., Refractories Division. Application for Permit to Operate a Facility that is a Stationary Source of Air Contamination at Augusta, Georgia. Submitted to Georgia Dept. of Natural Resources, Air Quality Control Section, Atlanta, Georgia. January 23, 1974.

15. Jennings, M. S. Trip Report: Babcock and Wilcox Company, Refractories Division, Augusta, Georgia. Radian Corp. Durham, N.C. December 3, 1979.

16. Jennings, M. S. and Laube, A. H. Observations of six refractory plants. November, December 1979.

17. Wilson, H. H. and L. D. Johnson. Characterization of Air Pollutants Emitted from Brick Plant Kilns. American Ceramic Society Bulletin. 54: 990-991, 994. November 1975.

18. Semrau, K. T. Emissions of Fluorides from Industrial Processes -- A Review. Journal of the Air Pollution Control Association. 7 (2): 92 - 108. August 1957.

19. Routschka, G., C. Buttgereit and V. Berger. Der Gehalt an Floor in feverfesten Tonen und Schamotte und die Beeinflussung der Fluorabgabe beim Brand der Schamotteerzeugnisse. [Fluorine Content of Refractory Clays and Fluorine Emission During Firing of Fire Clay Products.] Sprechasaal fue Keramik Glas, Email Silikate. (Coburg, W. Germany) 103 (20): 901-906.

20. Reference 17

21. Norton, F. H. Refractories. 4th ed. New York, McGraw-Hill, 1968. p. 189.

22. Research Triangle Institute. A Screening Study to Develop Background Information to Determine the Significance of Castable Refractories Manufacturing. RTI Project No. 41U-762-Task 1. Research Triangle Park, N.C. Prepared for the U.S. Environmental Protection Agency. December 1972. p. 2-6.
23. U.S. Environmental Protection Agency, Emission Standards and Engineering Division. Source Category Survey of the Mineral Wool Manufacturing Industry (Draft). Research Triangle Park, N.C. October 1979.
24. Reference 15
25. U.S. Dept. of Commerce, Bureau of the Census. 1977 Census of Manufactures, Industry Series, Nonclay Refractories. MC77-1-32E-6(P). Washington, D.C. June 1979.
26. The Refractories Institute. Refractory Volume-to-Weight Conversion Factors. TRI News Bulletin, 4: 2. June 1968.
27. Reference 9. p. 77 -78.
28. Energy and Environmental Analysis. Source Category Survey for the Clay and Brick Manufacturing Industry (Draft). Prepared for U.S. Environmental Protection Agency, Contract 68-02-3061. Durham, N.C. September 1979. Table 5-16.
29. Reference 17.
30. Jennings, M. S. Trip Report: Kaiser Refractories, Moss Landing, California. Radian Corporation. Durham, North Carolina. February, 1980.
31. Moore, R. F. Dust and Pollution Control. Globe Refractories, Inc. Newell, W.V. (Presented at Technical Review and Performance Assessment of Globe Refractories, Inc. Air and Water Pollution Control Facilities. Chester, West Virginia. June 13, 1978.) 20 p.
32. Reference 3
33. Ensor, David S. Ceilcote Ionizing Wet Scrubber Evaluation. U.S. Environmental Protection Agency. Research Triangle Park, N.C. EPA-60017-79-246. November 1979. p. 5-2, 5-3.

34. Reference 2. p. 8.3-3.
35. Reference 31. p. 19.
36. Reference 17.
37. Ryckman, Edgerley, Tomlison and Associates. Sampling of Particulate Emissions from an Electric Arc Furnace Ceramics Operation at C-E Refractories, St. Louis, Missouri. R.E.T.A. -510. St. Louis, Missouri.
38. Reference 3.
39. Reference 22. p. 2-5.
40. Reference 2. p. 8.5 - 1.

6. EMISSION CONTROL SYSTEMS

The various types of air pollution control equipment currently in use in the refractory industry to control airborne emissions are briefly reviewed in this section.

The three major refractory brick firing (kiln) emissions of concern are: particulate matter, sulfur oxides, and hydrogen fluoride. The other pollutants resulting from kiln operations are primarily combustion products. If good combustion practices are followed, carbon monoxide and nitrogen oxides are not emitted at levels which constitute a pollution problem.

Tars and pitch are used in the preparation of certain products. Particulate and higher molecular weight organic emissions are generated from these processes. Some of these emissions occur when the refractory brick or shape is impregnated with tar or pitch, and some occur when the tar bonded bricks are tempered in an oven.

When clays or nonclay minerals are fused in an electric arc furnace there are particulates emitted from the molten mass.

A molten stream of clay, such as kaolin, may also be formed into very fine threads called ceramic fiber. Particulates and higher molecular weight organic compounds are emitted from three processes involved in ceramic fiber fabrication; melting, fiberization and curing in ovens.

There are many types of air pollution control equipment available to control emissions from these various manufacturing processes. Details of these processes may be found in Chapter 4. The most important of the control devices now in use are discussed in the following sections.

6.1 CONTROL APPROACHES

6.1.1 Refractory Brick Kilns

Refractory brick kilns are generally uncontrolled. Kiln processes emit a variety of pollutants depending upon the composition of the clays and other raw materials being fired. But most formulas and processes will result in a low level of particulate and an insignificant level of combustion products. Specific levels are detailed in Chapter 5.

However, if sulfur compounds are present in the clays or other raw material or if sulfur containing compounds are added to the mixture used to form the refractory, these sulfur compounds will be oxidized and discharged in the stack gases. Fluorides will also be found in the stack gases if they are present in the raw materials.

Controls are not used on refractory tunnel kilns because the levels of particulate and gaseous emissions do not normally exceed state regulations. However, in one plant the combination of gaseous emissions and particulates has caused opacity to exceed 20 percent and a control device is required.[1] An ionizing wet scrubber (IWS) is used to control particulates and gaseous emissions from kilns firing ladle brick. Raw clay containing sulfur and other acid producing compounds is used in the manufacture of ladle brick. This clay, frequently used for ladle brick, contains high quantities of sulfides, fluorides, and nitrogenous compounds. The use of this clay is, in general, atypical of the clays used in refractory brick.

Each IWS unit is a multi-stage affair with a quench unit, three wet scrubbers, and two separate ionizers. With the exception of a few critical components which must be metallic, each IWS is constructed of Duracor fiberglass reinforced plastic (FRP). The ionizer sections themselves consist of charging wires strung vertically between plates. These components, like all other metallic parts in contact with the gas stream, are constructed of Hastelloy C276 alloy for maximum corrosion resistance. A two-year life of the plates is expected. Replacement cost for the plates will run upwards of $50,000. Total power consumption of a single unit containing two ionizers is approximately 10 kw. Wires are replaced at more frequent intervals depending on wear and breakage. All metallic parts are subject to corrosion. Replacement of corroded parts may be a significant problem and expense, depending upon the actual gases being controlled.[2]

Particulate removal for the IWS system is about 87 percent. Fluoride removal is better than 99 percent. Sulfur dioxide removal is 50 percent. The requirement at this plant was to reduce stack opacity and particulate to acceptable levels and this was accomplished.[3]

The IWS system generates an acidic liquor which must be treated before disposal.

6.1.2 Tar and Pitch Operations

As described in Chapter 4, tar and pitch are used for impregnation and bonding of bricks. Volatile organic aerosols are generated in the impregnating pressure vessels and organic aerosols are produced when these bricks are tempered in an oven. If inorganic particulate is not a problem an incinerator may be used. Incinerators usually exceed 95 percent efficiency based on destruction of such organic aerosols.[4]

6.1.3 Fused Cast Refractory Production

The electric arc furnaces generate particulates which are drafted away from the furnace with large volumes of air. These large volumes of air, which are required to capture the emissions, also cool the airflow so that fabric filters may be used. A typical baghouse used in such an application would have the specifications summarized in the following table:[5]

TABLE 6-1

No. of Bags	240	
Air to Cloth Ratio:	2.5 to 1	
Maximum Operating Temperature:	90 degrees C	(200 degrees F)
Normal Operating Temperature:	55 to 60 degrees C	(130 to 140 degree F)
Baghouse Capacity:	355 cubic meters/min.	(12,500 cfm)
Pressure Drop:	1500 pascal	(6 inches W.G.)
Dust Type:	Alumina Oxide	
Blowing Pressure:	6.2 to 6.9 x 10^5 pascal	(90 to 100 PSIG)
Installed Cost:	$37,000 (1976)	

Efficiency of fabric filters often exceeds 99.5 percent.[6] Overall control efficiency would depend upon how much of the emission was captured at the source. This data is not usually available. Two of these filters would be used to control the emissions generated during the production of approximately 6000 lbs per hour of fused cast product.[7]

6.1.4 Ceramic Fiber Manufacture

A molten stream of kaolin is converted into very fine threads called ceramic fiber as described in Chapter 4. There are three steps in the process: melting, fiberization, and oven curing.

The emissions generated in the melting process are similar to those described in the previous section. They are controlled with fabric filters as described in 6.1.3.

In the blowchamber small pieces of the fine thread are formed and introduced into an air stream. These particulates may be removed by means of a filter. The collected particles may be recycled.

The emissions described above are controlled with fabric filters or similar devices.[8] Efficiency exceeding 99 percent is commonly achieved with such equipment.[8,9] Similar efficiency would be expected in this application.

In the curing oven small particles of ceramic fiber are broken off or separated during the handling and forming of the fiber blankets. An oil is used in this process and higher molecular weight organics are emitted.

A fabric filter followed by incineration would be required. Overall efficiency exceeding 95 percent would be expected based on normal engineering design practice.[10]

6.2 ALTERNATIVE CONTROL METHODS

As can be seen each process described above has certain requirements which can be best met by the controls now in use. Other methods of control may be introduced as conditions warrant. But the need for developing any new control technology is not likely.

6.3 THE BEST SYSTEM OF CONTROL TECHNOLOGY

The best control technology is summarized in Table 6-2 and discussed below. The item letters refer to the table as indicated.

1. The ionizing wet scrubber (IWS) is listed because this is the only plant in the industry controlling brick kiln emissions. This plant

uses a special clay to produce ladle brick. Particulate and opacity exceeded the state limits. This is not a recommendation to consider an IWS for kiln emissions in general. Kiln emissions do not generally require control.

2. The low efficiency of sulfur dioxide removal is acceptable because the control device is installed to reduce particulate and opacity. Reduction in sulfur dioxide is not a requirement. The IWS is not recommended as the best system of control technology for sulfur dioxide. Sulfur oxides are not generally at a level requiring control.

3. The IWS removes a high level of fluoride but fluorides are generally not regulated.

4. The details of the control devices used by A.P. Green on tar and pitch processes were not available at the time this report was written. But incinerators on similar organic compounds in other industries achieve 95 percent efficiency of destruction for continuous operation.[15]

5. Fabric filter efficiency was not available on this baghouse. But 99 percent control device efficiency is commonly accepted engineering practice.[16] The capture efficiency of the associated hoods is not known. Therefore this is not an overall efficiency.

6. No filter was used at Babcock & Wilcox on the melting furnace. But the requirements would be similar to the other electric arc furnace applications in the industry.

7. There was only one filter installed on one of several lines at Babcock & Wilcox at the time of the plant visit. This was a prototype unit and efficiency of the device was not available.

8. No filter was in use on the oven at Babcock & Wilcox but a fabric filter would be commonly accepted engineering practice. Efficiency would be expected to be at least 99 percent.[17]

9. No incinerator was installed at Babcock & Wilcox. And details as to the control of these higher molecular weight organic compounds in this industry are not available. The Best System of control would involve technology transfer. Incinerators are being used on similar compounds at efficiencies greater than 95 percent.[18]

TABLE 6-2 BEST SYSTEMS OF CONTROL TECHNOLOGY

Process	Emission	Control Device	Percent Efficiency of the Control Device	Plant Location & Contact
Refractory Brick Kilns	Particulate	IWS^{a}	87	Globe Refractories, Inc.^{11} P.O. Box D Newell, West Virginia (304) 387-1160 Mr. S.C. Porter, Vice President
	Sulfur Oxide	IWS	50^{b}	
	Fluoride^{c}	IWS	99	
Tar and Pitch Impregnator and Curing Ovens	Higher Molecular Weight Organic Compounds	Incinerator	95+^{d}	A.P. Green Refractories Company^{12} Green Boulevard Mexico, MO 65265 (314) 473-3626 Mr. Robert Besalke Environmental Manager
Electric Arc Furnace	Particulate	Fabric Filter	99^{e}	C-E Refractories^{13} 101 Ferry Street St. Louis, MO 63147 Mr. D. Seets Process Engineer
Ceramic Fiber	Particulate	Fabric Filter	99^{f}	Babcock & Wilcox^{14} Old Savannah Road Augusta, Georgia 30903
Melting Furnace	Particulate	Lint Cage	-^{g}	
Blowchamber	Particulate	Fabric Filter	-^{h}	
Oven	High Molecular Weight Organic Compounds	Incinerator^{i}	95+	

6.4 REFERENCES

1. Moore, R. F. Dust and Pollution Control. Globe Refractories, Inc. Newell, W.V. (Presented at Technical Review and Performance Assessment of Globe Refractories, Inc. Air and Water Pollution Control Facilities. Chester, West Virginia. June 13, 1978.) 20 p.
2. Jennings, M. S. Trip Report: Globe Refractories, Newell, West Virginia. Radian Corp. Durham, N.C. December 5, 1979.
3. Reference 1
4. Sidlow, A. F. Source Test Report Conducted at Fasson Products, Division of Avery Corporation, Cucamonga, CA. San Bernadina County Air Pollution Control District, San Bernadino, CA. Engineering Evaluation Report 72.5. January 1972.
5. Jennings, M. S. Trip Report: C-E Refractories, St. Louis, Missouri. Radian Corp. Durham, N.C. December 11, 1979.
6. Moore, W. W. and N. W. Frisch. Air Pollution Control Programs and Systems. In: Industrial Pollution Control Handbook, Lund, H. F. (ed.). New York, McGraw-Hill. 1971. p. 5 - 16.
7. Ryckman, Edgerley, Tomlinson and Associates. Sampling of Particulate Emissions from an Electric Arc Furnace Ceramics Operation at C-E Refractories, St. Louis, Missouri. R.E.T.A.- 510. St. Louis, Missouri.
8. Jennings, M. S. Trip Report: Babcock and Wilcox Company, Refractories Division, Augusta, Georgia. Radian Corp. Durham, N.C. December 3, 1979.
9. Reference 6
10. Reference 4
11. Reference 1
12. Letter and attachments from Elder, H. J. Pennsylvania Bureau of Air Pollution Control, to Ashbaugh, R. A., A. P. Green Refractories Co. October 4, 1974. A. P. Green Co. refractory processes.
13. Reference 5
14. Reference 8
15. Reference 4

16. Reference 6
17. Reference 6
18. Reference 4

7. EMISSIONS DATA

7.1 AVAILABILITY OF DATA

Relatively few emission measurements are available for refractory manufacturing processes. There are four main sources of emission data: 1) National Emissions Data System (NEDS), 2) Compliance Data System (CDS), 3) test data on file with state or local agencies, and 4) information and test data obtained directly from the refractory companies.

Emissions and emission rates by SIC number, for specific plants and specific emission points can be obtained through the NEDS. Other useful information contained in NEDS reports include control equipment, collection efficiencies, and fuel type. NEDS is not always up-to-date and the current test results are not always available.

Information on the compliance status of point sources can be obtained from the CDS. By SIC code, this system identifies the sources and tells whether a point source is in compliance, out of compliance, or status unknown in reference to federal, state, or local regulations. As with NEDS, CDS does not always have the most current data on file. This delay is caused by the time necessary for companies to file test results with the states and for the states to file them on computer.

State or local agencies have information on the most current test data and permit applications. Emission test data may also be obtained directly from the companies involved.

Available emission source test data for the refractories industry has been summarized in Table 7-1. If this project continues on into Phase II a substantial amount of emissions test data must be developed.

7.2 SAMPLE COLLECTION AND ANALYSIS

Particulate, SO_2, and HF sampling and analysis techniques are all EPA reference methods:

Method 1:	Sample and Velocity Traverses for Stationary Sources.
Method 2:	Determination of Stack Gas Velocity and Volumetric Flowrate.

TABLE 7-1 EMISSION SOURCE TEST DATA

Test Locations	Number of Tests	Test Method	Comments
Stack of perodic kiln[1]	3	EPA Method 5	Isokinetic plus or minus 10%
Stack of tunnel kiln to IWS and outlet of IWS[2]	18	In-stack filters	For mass concentration also included Orsat CO_2, O_2, CO.
Stack of tunnel kiln to IWS and outlet of IWS[3]	16	Particle size	Cascade impactors and Aerosol size analyzer
Exhaust stack over electric arc furnace[4]	2	Velocity and particulate filter	(Not method 5)

Method 3: Gas Analysis for CO_2, O_2, Excess Air and Dry Molecular Weight.

Method 5: Determination of Particulate Emissions from Stationary Sources.

Method 6: Determination of SO_2 Emissions from Stationary Sources.

Method 8: : Determination of H_2SO_4 Mist and SO_2 Emissions from Stationary Sources.

Method 13a: Determination of Total Fluoride Emissions from Stationary Sources SPADNS Zirconium Lace Method.

Method 13b: Determination of Total Fluoride Emissions from Stationary Sources Specific Ion Electrode Method.

Particulate size is of importance because small particles, less than 5 micrometers in size, are carried into the human lung. There is no standard EPA method for determining particle size. However, the Cascade impactor can be used for sizes between 0.4 and 10 micrometers and recent developments such as the Coulter Counter and Thermosystems aerosol size analyzer have been used for particles between 0.1 and 1 micrometer.

7.3 REFERENCES

1. Environmental Testing, Inc. Source Sampling Report for North State Pyrophyllite Co., Inc. Charlotte, N.C. August 1978.
2. Moore, R. F. Dust and Pollution Control. Globe Refractories, Inc. Newell, W.V. (Presented at Technical Review and Performance Assessment of Globe Refractories, Inc. Air and Water Pollution Control Facilities. Chester, West Virginia. June 13, 1978.) 20 p.
3. Reference 2
4. Ryckamn, Edgerley, Tomlinson and Associates. Sampling of Particulate Emissions from an Electric Arc Furnace Ceramics Operation at C-E Refractories, St. Louis, Missouri. R.E.T.A.- 510. St. Louis, Missouri.

8. STATE AND LOCAL REGULATIONS

Essentially all of the states have some form of regulation to limit the emission of particulates from industrial processes. Particulate matter is the primary pollutant of concern for the refractory industry.

Particulates are generated during raw material processing. Particulate emissions resulting from fuel combustion are usually insignificant because process heating requirements are met by combustion of clean fuels such as natural gas and distillate oil. Fuel combustion also generates oxides of nitrogen, carbon and sulfur. And higher molecular weight organic compounds, fluorides and additional sulfur present in the raw materials, may be emitted during processing.

Most of the states where refractory plants are located regulate particulates from processing operations by a process weight regulation such as $E = 4.10P^{0.67}$ or $E = 3.59P^{0.69}$, where E equals the allowable emission rate in pounds per hour and P equals the process weight in tons per hour. The allowable quantities of particulates, based on 4.5 Mg per hour (five tons per hour) of process weight are presented in Table 8-1. In addition to emissions based on process weight many states allow emissions in proportion to the amount of fuel used in combustion. The exact wording of this regulation varies from state to state but it is frequently restricted to indirect heating such as boilers. Since the fuel used in refractory kilns is for direct heating of the product it has been assumed that only the process regulation applies. (Emissions based on indirect fuel combustion are the same order of magnitude as those based on process weight).

A summary of other current state regulations which would effect the refractories industry is also presented. Most states have some form of visible emission regulation. This is usually twenty percent opacity, corresponding to number one Ringlemann, as an upper limit. In one plant

TABLE 8-1 SUMMARY OF STATE EMISSION REGULATIONS PERTAINING TO NEW SOURCES IN THE REFRACTORY INDUSTRY

State	Number of Plants	General Process Regulation[a]	Visible Emissions (opacity)	Fugitive Dust	Particulate From Process[c]		Sulfur Oxides[b]	
					g/min	(lbs/hr)	g/min	(lbs/hr)
Georgia	11	$E = 4.1P^{0.67}$	20%[d]	NR	70	(9.3)[e]	454	(60)[f]
Missouri	15	$E = 4.1P^{0.67}$	20%	No visible particulates beyond premises	91	(12)	756	(100)
New Jersey	10	NR	NR	NR	45	(6)	3175	(420)
New York	8	$E = 3.91P^{0.67}$	20%	NR	83	(11)		
North Carolina	3	$E = 4.1P^{0.67}$	20%	Reasonable Precautions	91	(12)	52	(6.9)[d]
Ohio	50	$E = 4.1P^{0.67}$	20%	Reasonable Precautions	91	(12)		
Pennsylvania	69	0.04 g/scf	20%	Reasonable Precautions	53	(7)	756	(100)
Tennessee	6	$E = 3.59P^{0.62}$	20%	NR	113	(15)	756	(100)

(a) E = Allowable Emission (lb/hr) P = Process rate (tons/hr)
(b) Based on 20,000 scfm - except North Carolina
(c) Based on Process weight of 33,730 Mg/yr (37,230 tons/yr) or 4.5 Mg/hr (5 tons/hr)
(d) Based on fuel burning regulation
(e) For new kaolin process
(f) By formula depending on stack height - example using 50 ft. stack

NR = Not regulated

in West Virginia the opacity regulation was the most restrictive regulation. And the kilns in this plant have been equipped with IWS.[1] However, most uncontrolled kiln stacks and other point sources in the refractory industry are below 20 percent opacity. And thus, opacity is not normally a restrictive regulation for this industry.

Sulfur oxides are generally either not regulated or are not restrictive at the levels found in most kiln stack emissions. "Reasonable precautions" are generally required to prevent fugitive emissions. State or local regulations controlling carbon monoxide, fluorides and the nitrogen oxides for process emission sources are essentially nonexistent. Therefore, the only effect of present regulations on the national emissions from the refractory industry is to reduce the level of particulates. The effect of these regulations on the three most important pollutants is summarized below:

Table 8-2

ESTIMATED NATIONAL EMISSION FOR UNCONTROLLED AND CONTROLLED SOURCES

	Mg/yr	ton/yr
Uncontrolled particulate	4000	4500
Controlled particulate	1600	1800
Uncontrolled sulfur oxides	1600	1800
Uncontrolled fluorides	1100	1200

As previously indicated, in the refractory industry, the other products of combustion are not generally regulated. In the case of fuel oil, most states require that a specific level of sulfur content not be exceeded and this in effect limits the sulfur emissions from this source.

8.1 REFERENCE

1. Jennings, M. S. Trip Report: Globe Refractories, Newell, West Virginia. Radian Corp. Durham, N.C. December 5, 1979.

APPENDIX A

SIC 3255 CLAY REFRACTORIES

1. A. P. Green Refractories
Green Blvd
Mexico, Missouri 65265
(314) 473-3626
Sales: $67.0
Industry %: 9.43
Employment: 1000 - 2499

2. Babcock & Wilcox Co. Inc.
Old Savannah Rd
Augusta, Georgia 30903
(404) 798-8000
Sales: $52.6
Industry %: 7.41
Employment: 1000 - 2499

3. Kaiser Aluminum & Co.
203 E Love Street
Mexico, Missouri 65265
(314) 581-1250
Sales: $26.3
Industry %: 3.70
Employment: 500 - 999

4. Plibrico Co. Inc.
1800 North Kingsbury
Chicago, Illinois 60614
(312) LI9-7014
Sales: $20.5
Industry %: 2.89
Employment: 100 - 249

5. Harbison Walker Refractrs
Vandalia Works, Box 29
Vandalia, Missouri 63383
(314) LY4--6425
Sales: $20.1
Industry %: 2.83
Employment: 250 - 499

6. Harbison Walker Refract
Bigler & 9th Ave
Clearfield, Pennsylvania 16830
(814) 765-4531
Sales: $18.7
Industry %: 2.63
Employment: 250 - 499

7. Harbisonn Walker Refractor
Westminister
Fulton, Missouri 62251
(314) 642-2276
Sales: $15.5
Industry %: 2.18
Employment: 250 - 499

8. France J H Refractors Co.
1969 France Rd
Snow Shoe, Pennsylvania 16874
(814) 387-6811
Sales: $14.1
Industry %: 1.99
Employment: 250 - 499

9. Globe Refractories Inc
Box D - Keniworth Plant
Newell, West Virginia 26050
(304) 387-1160
Sales: $13.2
Industry %: 1.86
Employment: 250 - 499

10. C-E Refractories
Box 828
Valley Forge, Pennsylvania 1942
(215) 337-1100
Sales: $10.6
Industry %: 1.49
Employment: 100 - 249

11. C-E Refractories
101 Ferry St
St. Louis, Missouri 63147
(314) 421-3272
Sales: $10.6
Industry %: 1.49
Employment: 100 - 249

12. Whitacre Greer Fireproofing
E. Lisbon St
Waynesburg, Ohio 44688
(216) 866-9331
Sales: $9.9
Industry %: 1.39
Employment: 100 - 249

13. Ferro/Amer Clay Formng Plt
E Duncan St
Tyler, Texas 75701
(214) 597-7237
Sales: $9.8
Industry %: 1.38
Employment: 100 - 249

14. C E Refractories
Highway 54 W
Vandalia, Missouri 63382
(314) 249-2866
Sales: $9.6
Industry %: 1.35
Employment: 100 - 249

15. A P Green Refractories
P O Box 7
Woodbridge, New Jersey 07095
(201) 634-0900
Sales: $9.3
Industry %: 1.31
Employment: 100 - 249

16. Johns Manville Prod Penn
Front St
Zelienople, Pennsylvania 16063
(412) 452-8650
Sales: $9.1
Industry %: 1.28
Employment: 100 - 249

17. Freeport Brick Co Inc
P O Box F Mill St Ext
Freeport, Pennsylvania 16229
(412) 295-2111
Sales: $8.5
Industry %: 1.20
Employment: 100 - 249

18. Illinois Products Co
Gooselake Twp
Morris, Illinois 60450
(815) 942-0200
Sales: $8.0
Industry %: 1.13
Employment: Unknown

19. Harbison Walker Refctrs
838 Campbell Ave
Portsmouth, Ohio 4562
(614) 354-3181
Sales: $7.8
Industry %: 1.10
Employment: 100 - 249

20.	General Refractories Co Folsom St N W Warren, Ohio 44483 (216) 847-0536	Sales: $7.4 Industry %: 1.04 Employment: 100 - 249
21.	Kaul Clay Co. Inc John F Kennedy Hwy Toronto, Ohio 43964 (614) 537-1555	Sales: $7.4 Industry %: 1.04 Employment: 100 - 249
22.	North American Refractories Farber, Missouri 63345 (314) 249-2912	Sales: $7.3 Industry %: 1.03 Employment: 100 - 249
23.	Findlay Refractories Co Findlay & Greene Sts X 517 Washington, Pennsylvania 15301 (412) 225-4400	Sales: $7.2 Industry %: 1.01 Employment: 100 - 249
24.	Ferro Corp/Electro Dv 16th & Railroad Sts Sebring, Ohio 44672 (216) 938-2101	Sales: $6.8 Industry %: .96 Employment: 100 - 249
25.	Mount Savage Refractories Grant Bldg Pittsburgh, Pennsylvania 15219 (412) 281-0246	Sales: $6.7 Industry %: .94 Employment: 100 - 249
26.	McDaniel Refractory Porcln 510 9 Ave Beaver Falls, Pennsylvania 15010 (412) 843-8300	Sales: $6.7 Industry %: .94 Employment: 100 - 249
27.	New Castle Refractories Co S Swansea Ave New Castle, Pennsylvania 16103 (412) 654-7711	Sales: $6.4 Industry %: .90 Employment: 100 - 249
28.	Harbison Walker Refractories P O Box 278 New Savage Wks Grantsville, Maryland 21536 (301) 895-5111	Sales: $5.8 Industry %: .82 Employment: 100 - 249
29.	A P Green Refractories St Eunice Rd Fulton, Missouri 65251 (314) 642-6667	Sales: $4.7 Industry %: .66 Employment: 50 - 99

30 Plibrico Co Inc
Rte 3 State Rte 140
Oak Hill, Ohio 45656
(614) 682-3555
Sales: $4.5
Industry %: .63
Employment: 20 - 49

31. Kittanning Brk Div Frport
R D 1
Reesdale, Pennsylvania 16229
(412) 295-2111
Sales: 4.4
Industry %: .62
Employment: 50 - 99

32. Green Refractories Co. Inc
2800 Alabama Ave
Bessemer, Alabama 35020
(205) 428-9175
Sales: $4.4
Industry %: .62
Employment: 50 - 99

33. New Castle Refractories Co.
P O Box 415
Newell, West Virginia 26050
(304) 387-2980
Sales: $4.3
Industry %: .61
Employment: 50 - 99

34. North American Refractories
13th St & Ashtabula
Ironton, Ohio 45638
(614) 532-3621
Sales: $4.1
Industry %: .58
Employment: 50 - 99

35. General Refractories Co
Main Road
Salina, Pennsylvania 15680
(412) 697-4547
Sales: $4.0
Industry %: .56
Employment: 50 - 99

36. Drexel Dynamics Corp
RFD 2
Kittanning, Pennsylvania 16201
(412) 543-2911
Sales: $4.0
Industry %: .56
Employment 50 - 99

37. Chicago Fire Brick Co
1467 Elston Ave
Chicago, Illinois 60622
(312) BR8-8000
Sales: $3.9
Industry %: .55
Employment: 100 - 249

38. Harbison Walker Refractories
Templeton, Pennsylvania 16259
(412) 868-2521
Sales: $3.7
Industry %: .52
Employment: 50 - 99

39. AFC Corp
5183 West Western Reserve
Canfield, Ohio 44406
(216) 533-5581
Sales: $3.7
Industry %: .52
Employment: 50 - 99

40. Swanks Hiram Sons Inc
Rt 480
Clymer, Pennsylvania 15728
(412) 254-4178
Sales: $3.4
Industry %: .48
Employment: 50 - 99

41. A P Greene Div US Gypsum
Baker Hill Hwy
Eufaula, Alabama 36027
(205) 687-5803
Sales: $3.3
Industry %: .46
Employment: 50 -99

42. Kek Refractories
4140 Brownsville Rd
Pittsburgh, Pennsylvania 15227
(412) 882-9409
Sales: $3.3
Industry %: .46
Employment: 50 - 99

43. North State Pyrophyllite
3514 W Wendover Ave
Greensboro, North Carolina 27407
(919) 299-1441
Sales: $3.3
Industry %: .46
Employment: 50 - 99

44. Electrical Refractories Co
550 E Clark
East Palestine, Ohio 44413
(216) 426-9433
Sales: $3.3
Industry %: .46
Employment: 50 - 99

45. A P Green Refractories
FM 1870/P O Box 277
Sulphur Springs, Texas 75482
(214) 488-3215
Sales: $3.3
Industry %: .46
Employment: 50 - 99

46 Louisville Fire Brick Wrks
Grahn, Kentucky 41142
(606) 286-4436
Sales: $3.2
Industry %: .45
Employment: 50 - 99

47. Harbison Walker Refractories
Bakerhill Hwy/ P O Box 168
Eufaula, Alabama 36027
(205) 687-3459
Sales: $3.1
Industry %: .44
Employment: 50 - 99

48. C E Raymond Bartlett Snow
333 State St
Chicago Hts, Illinois 60411
(312) 757-7880
Sales: $3.1
Industry %: .44
Employment: 50 - 99

49, Plibrico Co Inc
1300 New York Ave
Trenton, New Jersey 08638
(609) 393-7461
Sales: $3.1
Industry %: .44
Employment: 20 - 49

50. Mt Savage Refractories Sales: $3.1
P O Box 576 Industry %: .44
Mt. Savage, Maryland 21545 Employment: 50 99
(301) 2643571

51. Green Refractories Co. Inc Sales: $3.0
P O Box 128 Industry %: .42
Kimberly, Alabama 35091 Employment: 20 49
(205) 6473861

52. A P Green Refractories Sales: $2.8
2900 Waterville Rd Industry %: .39
Macon, Georgia 31206 Employment: 20 49
(912) 7816228

53. A P Green Refractories Sales: $2.8
Climax Div/Box 44 Industry %: .39
New Bethlehem, Pennsylvania 16242 Employment: 20 49
(814) 2751343

54. Swanks Hiram Sons Inc Sales: $2.8
Large Industry %: .39
Clairton, Pennsylvania 15025 Employment: 50 99
(412) 3844259

55. General Refractories Co. Sales: $2.5
300 N Collie St Industry %: .35
Troup, Texas 75789 Employment: 50 99
(214) 8423184

56. Drexel Refractories Inc Sales: $2.4
723 High St N W Industry %: .34
Carrollton, Ohio 44615 Employment: 50 99
(216) 6272184

57. Colorado Refractories Corp Sales: $2.3
309 S 11th St/Box 1001 Industry %: .32
Canon City, Colorado 81212 Employment: 20 49
(303) 2751555

58. DFC Ceramics Sales: $2.3
515 S. 9th/Box 110 Industry %: .32
Canon City, Colorado 81212 Employment: 20 49
(303) 2757525

59. North American Refractors Sales: $2.3
White Cloud, Michigan 49349 Industry %: .32
(616) 6896641 Employment: 20 49

60. Pryor-Giggey Co
10000 Santa Fe Springs Rd
Santa Fe Sprg, Claifornia 9-670
(213) 944-7981
Sales: $2.3
Industry %: .32
Employment: 20 - 49

61. Kaiser Aluminum & Chemical
165 E Park Ave
Niles, Ohio 44446
(216) 793-1339
Sales: $2.2
Industry %: .31
Employment: 50 - 99

62. Osceola Fire Brick Co
1012 Grant Bldg
Pittsburgh, Pennsylvania 15219
(412) 281-0246
Sales: $2.0
Industry %: .28
Employment: 20 - 49

63. A P Green Refractories
Pyro
Jackson, Onio 45640
(614) 286-3332
Sales: $2.0
Industry %: .28
Employment: 20 - 49

64. A P Green Refractories
P O Box 255
Oak Hill, Ohio 45656
(614) 682-7713
Sales: $2.0
Industry %: .28
Employment: 20 - 49

65. Osceola Fire Brick Co
Rt 56
Osceola Mills, Pennsylvania 16666
(814) 281-0246
Sales: $1.9
Industry %: .27
Employment: 20 - 49

66. A P Green Refractories
15225 Lincoln Way W
Massillon, Ohio 44646
(216) 832-7407
Sales: $1.7
Industry %: .24
Employment: 20 - 49

67 Whitacre Greer Fireproofing
400 E Lisbon
Magnolia, Ohio 44643
(216) 866-9331
Sales: $1.7
Industry %: .24
Employment: 20 - 49

68. Refractory Sales & Service
Hwy 150/Box 885
Bessemer, Alabama 35020
(205) 425-2476
Sales: $1.6
Industry %: .23
Employment: 50 - 99

69. Alsey Refractories Co Inc
Hwy 106
Alsey, Illinois 62610
(217) 742-5501
Sales: $1.6
Industry %: .23
Employment: 20 - 49

70.	General Refractories Co Rt 220 Sproul, Pennsylvania 16682 (814) 239-2111	Sales: $1.5 Industry %: .21 Employment: 20 - 49
71.	Hartford Refractories 31 Tobey Rd Bloomfield, Connecticut 06002 (203) 677-4631	Sales: $1.4 Industry %: .20 Employment: 20 - 49
72.	Riverside Clay Co Inc Hwy 78/P O Box 551 Pell City, Alabama 35125 (205) 338-3366	Sales: $1.4 Industry %: .20 Employment: 20 - 49
73.	Columbia Fire Brick Co Rt 21/P O Box 207 Dover, Ohio 44622 (216) 878-5544	Sales: $1.4 Industry %: .20 Employment: 20 - 49
74.	A P Green Refractories Troy, Idaho 83871 (208) 835-2201	Sales: $1.3 Industry %: .18 Employment: 20 - 49
75.	Refractory Products 2 12 E Main St Carpentersville, Illinois 60110 (312) 426-8191	Sales: $1.3 Industry %: .18 Employment: 20 - 49
76.	Donoho Clay Co Inc 1100 W 10th St/ Box 843 Anniston, Alabama 36201 (205) 237=8565	Sales: $1.2 Industry %: .17 Employment: 20 - 49
77.	Chicago Fire Brick Co. 1269 W Lemoyne Ave Chicago, Illinois 60636 (312) 846-6501	Sales: $1.2 Industry %: .15 Employment: 20 - 49
78.	Missouri Minerals Processg High Hill, Missouri 63350 (314) 585-2300	Sales: $1.1 Industry %: .15 Employment: 20 - 49
79.	Applied Ceramics Inc P O Box 29664 Atlanta, Georgia 30329 (404) 448-6888	Sales: $0.9 Industry %: .13 Employment: 20 - 49
80.	Darco Corp 160 Visger Ave River Rouge, Michigan 48218 (313) 386-8300	Sales: $0.9 Industry %: .13 Employment: 20 - 49

APPENDIX B

SIC 3297 NONCLAY REFRACTORIES

1. Babcock & Wilcox Co.
Old Savannah Rd
Augusta, Gerogia 30903
(404) 798-8000
Sales: $61.1
Industry %: 5.41
Employment: 500 - 999

2. Basic Refractories
Country Road
Maple Grove, Ohio 44815
(419) 986-5111
Sales: $52.9
Industry %: 4.68
Employment: 500 - 999

3. Harbison Walker Refractories
1200 Patapsco Ave
Baltimore, Maryland 21225
(301) 355-8500
Sales: $42.3
Industry %: 3.75
Employment: 500 - 999

4. Quigley Co Inc
Bordentown Ave
Old Bridge, New Jersey 08857
(201) 257-1227
Sales: $35.6
Industry %: 3.15
Employment: 250 - 499

5. CE Refractories
101 Ferry St
St Louis, Missouri 63147
(314) 421-3272
Sales: $35.2
Industry %: 3.12
Employment: 250 - 499

6. Harbison Walker Refractories
Mount Union , Pennsylvania 17066
(814) 542-2528
Sales: $35.2
Industry %: 3.12
Employment: 250 - 499

7. Kaiser Refractories
Chemical Rd
Plymouth Mtg, Pennsylvania 19462
(215) 825-4500
Sales: $33.7
Industry %: 2.98
Employment: 250 - 499

8. Ferro Corp/Electro Div
Willett Rd
Buffalo, New York 14218
(716) 825-7900
Sales: $33.5
Industry %: 2.97
Employment: 250 - 499

9. Remmey Div A P Green Refractories
Hedley & Delaware River
Philadelphia, Pennsylvania 19137
(215) JE5-0100
Sales: $32.4
Industry %: 2.87
Employment: 250 - 499

10. General Refractories Co
3401 7th St/Box 1673
Baltimore, Maryland 21225
(301) 355-8700
Sales: $31.2
Industry %: 2.76
Employment: 250 - 499

11. North American Refractories Sales: $29.6
RFD 1 Industry %: 2.62
Womelsdorf, Pennsylvania 19567 Employment: 250 - 499
(215) 589-2535

12. Kaiser Refractories Sales: $26.3
41738 Esterly Dr Industry %: 2.33
Columbiana, Ohio 44408 Employment: 250 - 499
(216) 549-3941

13. Swank Refractories Co Sales: $24.3
101 Swank Court Industry %: 2.15
Johnstown, Pennsylvania 15902 Employment: 250 - 499
(814) 536-5321

14. Swank Refractories Co Sales: $24.3
101 Swank Court Industry %: 2.15
Johnstown, Pennsylvania 15902 Employment: 250 - 499
(814) 536-5321

15. General Refractories Co Sales: $23.4
Main St Industry %:
Claysburg, Pennsylvania 16625 Employment: 250 - 499
(814) 239-2121

16. Kaiser Aluminum & Co Sales: $20.3
Highway 1 Industry %: 1.80
Moss Landing, California 95039 Employment: 250 - 499
(408) 633-2413

17. Corhart Refractories Co Sales: $20.3
1600 W Lee St Industry %: 1.80
Louisville, Kentucky 40210 Employment: 250 - 499
(502) 778-3311

18. Charles Taylor Sons Co Inc Sales: $19.3
P O Box 457 Industry %: 1.71
South Shore, Kentucky 41175 Employment: 100 - 249
(606) 932-3131

19. Swank Refractories Co Sales: $17.5
24th & Clark Ave Industry %: 1.55
Wellsville, Ohio 43968 Employment: 100 - 249
(216) 532-1571

20. Corhart Refractories Co Sales: $15.5
Rt 1 Box 28 Industry %: 1.37
Buckhannon, West Virginia 26201 Employment: 250 - 499
(304) 472-4000

21. Carborundum Co
501 New York Ave Box 157
Falconer, New York 14733
(716) 665-2120
Sales: $15.1
Industry %: 1.34
Employment: 250 - 499

22. Carborundum Co
P O Box 187
Keasbey, New Jersey 08832
(201) 442-3380
Sales: $14.8
Industry %: 1.31
Employment: 250 - 499

23. Taylor Chas Sons Co
8361 Broadwell Rd
Cincinnati, Ohio 45244
(513) 251-4285
Sales: $14.5
Industry %: 1.28
Employment: 100 - 249

24. Harbison Walker Refractories
McDaniel Station Rd
Calhoun, Georgia 30701
(404) 629-0168
Sales: $14.4
Industry %: 1.27
Employment: 100 - 249

25. Harbison Walker Refractors
U S 31/Box 569
Ludington, Michigan 49431
(616) 843-2525
Sales: $14.0
Industry %: 1.24
Employment: 100 - 249

26. Harbison Walker Refractories
P O Box 311
Fairfield, Alabama 35064
(205) 785-3132
Sales: $14.0
Industry %: 1.24
Employment: 100 - 249

27. General Refractories
1000 N Clark Rd
Gary, Indiana 46401
(219) 949-8451
Sales: $13.6
Industry %: 1.20
Employment: 100 - 249

28. Harbison Walker Refractories
P O Box 397
Windham, Ohio 44288
(216) 326-2010
Sales: $13.2
Industry %: 1.17
Employment: 100 - 249

29. C-E Refractories
Farber, Missouri 63345
(314) 249-2866
Sales: $12.3
Industry %: 1.09
Employment: 100 - 249

30. Vesuvius Crucible Co
2216 Palmer St
Swissvale, Pennsylvania 15218
(412) 351-3200
Sales: $11.4
Industry %: 1.01
Employment: 100 - 249

31. Lava Crucible Refractories
Clay
Zelienople, Pennsylvania 16063
(412) 452-6050
Sales: $11.4
Industry %: 1.01
Employment: 100 - 249

32. Carborundum Co Inc
Hillview Ave
Latrobe, Pennsylvania 15650
(412) 537-3331
Sales: $10.8
Industry %: .96
Employment: 250 - 499

33. Harbison Walker Refractories
300 N 32nd St/P O Box B
Bessemer, Alabama 35020
(205) 428-6371
Sales: $10.0
Industry %: .89
Employment: 100 - 249

34. A P Green Refractories Co
6th St & Center
Tarentum, Pennsylvania 15084
(412) 224-8800
Sales: $9.3
Industry %: .82
Employment: 100 - 249

35. Interpace Corp
3000 1st Ave
Seattle, Washington 98121
(206) 682-9891
Sales: $7.1
Industry %: .63
Employment: 100 - 249

36. Combustion Engineering
Indus Hwy
Eddystone, Pennsylvania 19013
(215) TR4-0404
Sales: $6.6
Industry %: .58
Employment: 50 - 99

37. A P Green Refractories
2500 N Santa Fe/Box 1614
Pueblo, Colorado 81002
(303) 544-9043
Sales: $6.1
Industry %: .54
Employment: 50 - 99

38. Harbison Walker Refractories
5501 Kennedy
Hammond, Indiana 46323
(219) 932-8641
Sales: $5.6
Industry %: .50
Employment: 50 - 99

39. Kittanning Brk Dv Freeport
Adrian, Pennsylvania 16210
(412) 868-2501
Sales: $5.4
Industry %: .48
Employment: 50 - 99

40. General Refractories Co
Lehi, Utah 84043
(801) 768-3591
Sales: $5.4
Industry %: .48
Employment: 50 - 99

41. American Refractories Corp
Washington Ave
North Haven, Connecticut 06473
(203) 239-1624
Sales: $5.2
Industry %: .46
Employment: 50 - 99

42. Ross Tacony Crucible Co
Robbins & Milnor
Philadelphia, Pennsylvania 19135
(215) MA4-1010
Sales: $5.2
Industry %: .46
Employment: 50 - 99

43. Dolomite Brick Corp
232 E Market St
York, Pennsylvania 17405
(717) 848-1508
Sales: $5.2
Industry %: .46
Employment: 100 - 249

44. Harbison Walker Refractors
U S 40 S - Hile Work
North East, Maryland 21901
(302) 287-8161
Sales: $4.7
Industry %: .42
Employment: 50 - 99

45. North American Refractories
Mount Union, Pennsylvania 17066
(814) 542-2551
Sales: $4.6
Industry %: .41
Employment: 50 - 99

46. J. E. Baker
3964 County Rd 41
Millersville, Ohio 43448
(419) 638-2501
Sales: $4.4
Industry %: .39
Employment: 50 - 99

47. Carborundum Co Graphite Dv
P O Box 577
Niagara Falls, New York 14302
(716) 731-3221
Sales: $4.3
Industry %: .38
Employment: 100 - 249

48. Corhart Refractories
Bayou Casotte Ind Area
Pascagoula, Mississippi 39567
(601) 762-3122
Sales: $4.3
Industry %: .38
Employment: 50 - 99

49. Zirconium Corp of America
31501 Solon
Solon, Ohio 44139
(216) 248-0500
Sales: $3.8
Industry %: .34
Employment: 50 - 99

50. Ferro/Electro-Refrctrs Dv
Fiber Glass Rd
Huntington Beach, California 92648
(714) 847-3563
Sales: $3.5
Industry %: .31
Employment: 20 - 49

51. Kaiser Aluminum & Chem Co
7501 W 5th Ave
Gary, Indiana 46406
(219) 949-4507
Sales: $3.4
Industry %: .30
Employment: 50 - 99

52. Thermo Materials Corp
3584 McCall Place
Doraville, Georgia 30340
(404) 451-6101
Sales: $3.3
Industry %: .29
Employment: 20 - 49

53. Thermotect Co Inc
Box 178
Gibsonia, Pennsylvania 15044
(412) 443-5965
Sales: $3.0
Industry %: .27
Employment: 20 - 49

54. Allied Mineral Products
2626 Fisher Rd
Columbus, Ohio 43204
(614) 272-1054
Sales: $2.8
Industry %: .25
Employment: 20 - 49

55. C E Minerals
Pidgeon Point Rd
New Castle, Delaware 19720
(402) 652-3301
Sales: $2.6
Industry %: .23
Employment: 20 - 49

56. Universal Refractories
Wampum, Pennsylvania 16157
(412) 535-4374
Sales: $2.3
Industry %: .20
Employment: 20 - 49

57. General Refractories Co
1808 Moen Av
Joliet, Illinois 60435
(815) 725-5300
Sales: $2.3
Industry %: .20
Employment: 20 - 49

58. Interpace Corp
Highway 27
Mica, Washington 99023
(509) 924-2120
Sales: $2.2
Industry %: .19
Employment: 20 - 49

59. National Crucible Co Inc
Queen & Mermail Lane
Philadelphia, Pennsylvania 19118
(215) CH7-9200
Sales: $2.2
Industry %: .19
Employment: 20 - 49

60. C E Refractories
625 Illinois Ave
Aurora, Illinois 60506
(312) TW7-8487
Sales: $2.1
Industry %: .19
Employment: 20 - 49

61. Refractory Products 1
120 S Lincoln Ave
Carpentersville, Illinois 60110
(312) 426-6744

Sales: $1.8
Industry %: .15
Employment: 20 - 49

62. Interpace Corp
Victorville, California 92392
(714) 245-4262

Sales: $1.7
Industry %: .15
Employment: 20 - 49

63. A P Green Refractories
6315 Hiwhway 332 E
Freeport, Texas 77541
(713) 233-5861

Sales: $1.7
Industry %: .15
Employment: 20 - 49

APPENDIX C

List of Knowledgable Contacts

1. Mr. Bradford Tucker
The Refractory Institute
1102 One Oliver Plaza
Pittsburgh, PA 15222
(412) 281-6787

2. Mr. Robert Besalke
A. P. Green Refractories Co.
Green Blvd.
Mexico, MO 65265
(314) 473-3626

3. Mr. Robert Moore
Globe Refractories
P.O. Box D
Newell, WV 26050
(304) 387-1160

4. Mr. H. S. James
Kaiser Refractories
Kaiser Center: 300 Lakeside Drrive
Oakland, CA 94643
(415) 271-3463

5. Mr. J. T. Elmer
Kaiser Refractories
Moss Landing, CA 95039
(408) 633-2413

6. Mr. G. H. Chesnut
Babcock and Wilcox Company, Refractories Div.
Old Savannah Road, P.O. Box 923
Augusta, GA 30903
(404) 798-8000

7. Dr. Daniel K. Clift
North American Refractories
Hanna Building, E. 14th and Euclid
Cleveland, OH 44115

8. Mr. Robert Purcell
Energy and Environmental Analysis
2607A Carver Street
Durham, NC 27705
(919) 471-2506